# MAPPING OF ENVIRONMENTAL SENSITIVITY IN THE WESTERN ARABIAN GULF USING GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR OIL SPILL RESPONSE

BY

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*Dedication to*

*My Beloved Wife and Family*

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# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

**CEW** : Center of Environment and Water

**ESI** : Environmental Sensitivity Index

**ESRI** : Environmental Systems Research Institute, Inc.

**GOSPs** : Gas and Oil Separation Plants

**GIS** : Geographic Information System

**IMO** : International Maritime Organization

**IOGP** : International Association of Oil & Gas Producers

**IPICEA** : International Petroleum Industry Environmental Conservation Association

**ITOPF** : The International Tanker Owners Pollution Federation

**NCGIA** : The National Center for Geographic Information and Analysis

**NOAA** : National Oceanic and Atmospheric Administration

**POI** : Point of Interest

**ROI** : Region of Interest

**WGS** : The World Geodetic System

# ABSTRACT


Full Name : [Sudibyo Solikan Sardi]

Thesis Title : [Mapping Environmental Sensitivity in the Western Arabian Gulf using Geographic Information System (GIS) for Oil Spill Response]

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The Western Arabian Gulf (hereinafter after the Gulf) has several sensitive ecosystems such as coral reefs, seagrass beds, salt marshes and mangroves. Several economic activities, including oil-related facilities, also exist along the coastal areas in the Gulf. Impact from oil spills is one of the important environmental risks that potentially may affect marine or terrestrial ecosystems. Spills are caused by human activities. Spills may be caused by releases of oil from offshore platforms, submarine pipelines, drilling of wells, oil distribution processes, or sites of conflicts, among others.

There are several consequences of oil spills that can be harmful to the environment and economic activities, such as tainting marine ecosystems and edible species, losing amenity of recreational areas, and disturbing coastal industrial processes (desalination and power plants, etc.). In order to reduce the harmful effects of oil spills, it is necessary to know those locations needing to be protected immediately after an oil spill, and understand the relative sensitivity of different coastal areas. This necessitates appropriate land-use regulation including sensitivity zoning and planning for oil spill response scenarios. The action called for is to prepare oil spill response contingency planning, and thereby guide the sustainable use of coastal areas through appropriate land-use management.

This study responds to the lack of any published information on the environmental sensitivity of the Gulf coast to oil spills. The coastal areas of the Gulf experienced the worst oil spill in world history in 1991 and lessons can be drawn from that event and its aftermath. The aim of this study is to identify and characterize the environmentally sensitive areas along the Western Arabian Gulf coast using geographic information system (GIS) techniques. This mapping is directly applicable for oil spill response activities.

In this study, several parameters for a land-use planning (zoning) approach to assess environmentally sensitive areas in the Gulf was conducted by incorporating geographic information system (GIS) analysis with both remote sensing imagery and biotope mapping. The resulting environmental sensitivity map contains a compilation of analyses about shoreline type, biological resources, and socio-economic features with different Environmental Sensitivity Index (ESI) scoring.

The environmental sensitivity map has been generated using spatial distribution analysis to rank the sensitivity of an area and determine the cumulative sensitivity index. The resulting thematic map features different types of parameters and the sensitive areas with different sensitivity scores. Based on these results, the first rated priority areas that should be protected in case of oil spills are the following: Safaniyah, Khursaniyah-Jubail, Tarut Bay and the offshore islands viz., Karan, Kurayn, Jana and Jurayd Islands.

# ملخص الرسالة


**الاسم الكامل** : **سو دبيو سوليكان ساردي**

**عنوان الرسالة** : **تخطيط المناطق البيئيه الحساسه غرب الخليج العربي باستخدام نظم المعلومات الجغرافيه(GIS) للاستجابه للانسكابات النفطيه**

**التخصص** : **العلوم البيئية**

**تاريخ الدرجة العلمية** : **ديسمبر ٢٠١٥**

يتميز غرب الخليج العربي ( الخليج) باحتوائه للعديد من النظم البيئيه الحساسه مثل الشعب المرجانيه , الحشائش البحريه, المستنقعات المالحه ومنابت اشجار المانجروف . كما تتواجد العديد من الانشطه الاقتصاديه ذات الصله بالنفط على طول ساحله. لذا يعتبر انسكاب النفط احد القضايا البيئيه المهمه التي تؤثر على اليابسه والبحر معا في تلك المنطقه. يمكن حدوث الانسكابات النفطيه من منصات النفط البحريه, خطوط الانابيب المغموره, عمليات حفر الابار وغيرها من الانشطه. هناك العديد من الاثار المترتبه على عمليات الانسكابات النفطيه والتي يمكن ان تلحق الضرر بالنواحي البيئيه والاقتصاديه معا, وتشمل تلوث البيئه والاحياء البحريه, فقدان الراحه في المناطق الترفيهيه,واضرار بالعمليات الصناعيه( محطات التحليه وغيرها). وللحد من الاضرار الناتجه عن عمليات التسرب النفطي, فانه يتعين معرفة المناطق التي يجب حمايتها وكذلك معرفة مدى حساسية هذه المناطق لعمليات التسرب وذلك عن طريق رسم خرائط للاماكن البيئيه الحساسه. تحديد المناطق الحساسه والتخطيط الجيد يساعد على وضع خطط الاستجابه للطوارئ الناتجه عن عمليات التسرب وكذلك الاداره المستدامه للمناطق الساحليه.

في هذه الدراسه العديد من نهج التقييم التي تساعد على تقسيم المناطق البيئيه الحساسه في الخليج من خلال دمج التحاليل المتحصله باستخدام نظم العلومات الجغرافيه مع كل من صور الاستشعار عن بعد والخرائط الاحيائيه. خرائط الحساسيه البيئيه تحتوي على مجموعه من التحاليل عن انواع الشواطئ, الموارد الحيويه والخصائص الاجتماعيه والاقتصاديه باستخدام مؤشرات مختلفة للحساسية البيئية. خرائط الحساسية البيئية تشمل تحليل للتوزيع المكاني لترتيب مدى حساسية المناطق ومؤشر الحساسية التراكمي. النتائج اظهرت علاقة الخرائط مع المعايير البيئيه المختلفه وحساسية الاماكن بإظهار الاختلاف في درجات الحساسيه. واستنادا على ترتيب الحساسيه حسب الأولوية, فان اول المناطق التي يجب ان تكون محميه في حالة انسكاب النفط هي: السفانيه, خرسانية الجبيل, خليج وجزر تاروت, كاران, كورين, جانا, وجزر جريد.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Energy demands have driven oil-related exploration and production activities, as well as related shipping traffic in the Gulf and other areas that have important oil resources. As production increases in these areas, concurrently the transport of oil products increases both in volumes of crude and refined oil products, and in the number of ships used. Crude is also being transported from the offshore areas to the onshore facilities using submarine pipelines. All these factors have significantly contributed to the increased risk of marine oil spill incidents, especially placing at risk the coastal areas where the spills would accumulate. Thus, the potential impact from oil spills may affect not only in the watery environment but also the terrestrial area in the coastal zone (Kostka, et al., 2011).

The Gulf is host to many oil-related activities, such as oil exploration, ports, oil transportation (tanker traffic), oil distribution (pipelines), refineries, offshore production platforms, Gas and Oil Separation Plants (GOSPs), etc. Small- and large-scale accidental oil spills cannot be completely avoided given that several oil-related activities are taking place in the offshore areas along this coast. The coastal areas of the Gulf experienced the worst oil spill in world history, the 1991 Gulf oil spill which resulted from military conflict. That spill resulted in the spilling of an estimated 8 to 11 million barrels of crude oil into the northwestern Gulf between January and August of 1991 (Gerges, 1993; Readman et al., 1996; Sheppard, 1993). Even several years after the oil spill, the presence of residual oil was reported in the surface sediments in several coastal locations along the Saudi Arabian coast (Villeneuve, 2007), and macro benthic communities are yet to completely recover from the impact of that oil spill (Joydas, et al., 2011).

Oil spills can harm the natural environment including the marine ecosystem (Gundlach, et al., 1993; Brown, et al., 2011). Spills also can affect wildlife through physical contact, inhalation, ingestion and trans-cutaneous absorption, smothering of hairs and feathers, and damages of vital organ systems (Krupp and Abdulaziz, 2008). The Gulf has varied critical ecosystems such as coral reefs, seagrass beds, and mangroves. These ecosystems are essential for fish nurseries and turtle breeding, among others. These ecosystems should be protected from oil spills. In addition, there are many human environments that will be at risk in case of an accidental oil spills. Moreover, oil spill mitigation and recovery from spills in coastal areas are difficult. Accumulated spilled oil sticks to shoreline habitats such as mangrove stands or salt marshes (Saenger, 1994; Beisl, et al., 2003; Fingas, 2012).

In order to reduce the harmful consequences of oil spills and enhance the oil spill response preparedness, it is necessary to classify the coastal areas in terms of their sensitivity to oil spills and thereby prioritize the areas for protective response.

It has been reported that, shoreline type, biological resources such as habitat, and socio-economic features are three main components that should be considered in oil spill contingency plans and actual responses (Ornitz, and Champ, 2002). One of the most important approaches toward oil spill preparedness commonly used is environmental sensitivity mapping (Pourvakhshouri and Mansor, 2003; IPICEA, 2012). This type of mapping is a compilation of information about shoreline type, biological resources, and socio-economic features with different Environmental Sensitivity Index (ESI). Many studies have been reported on developing and using ESI maps for oil spill contingency planning that focused on shoreline type and sensitivity. These have included studies of the New Zealand Coastline (Tortell, 1990), Shetland Island, UK (Khrisnan, 1995), United States Coastline (Jensen, et al., 1998), Ras-Mohammed coastal zone, Egypt (Abdel-Kader, et al, 1998). Others have considered shoreline type and both the natural and human environment. These have included studies of the  Rio Grande de Norte State coastal area, Argentina (de Castro, et. al, 2004), Amazon Coast, Brazil (Souza, et al. 2004), São Paulo State coastline, Brazil (Carmona, et al, 2006), Cardoso Island State Park, Brazil (Wieczorek, et al., 2007), United Arab Emirates Coast, UAE (Jensen, et al., 2008), Iranian Coastline, Iran (Nouri, et al., 2009). Additionally, a web-GIS method was used interactively to compile information in the context of the Deep Water Horizon spill incident in the Gulf of Mexico (Nxumalo, et al. 2013).

The GIS method has successfully been applied to complement environmental sensitivity mapping. Most current research in this field applies a sensitivity classification scheme in accompaniment with a simple cartographic model as a map-based approach using GIS (Jensen, et.al, 1990, 1998; Souza, et al. 2004; Wieczorek, et al., 2007). The significant aspect of GIS is the ability of the software to integrate different spatial data with the standard tools and symbols. The purpose this data integration is to identify and describe spatial associations present in the data, and to use models for analysis and prediction of spatial condition (Beisl, et al., 2003).

## 1.2 Research Objectives

The main objective of this study was to identify and characterize the environmentally sensitive areas along the Gulf coast using geographic information system (GIS) methods. The resulting maps can be used for land-use planning and oil spill response planning. It is expected that this mapping will be useful to the authorities as well as responders from the region, particularly with respect to their developing oil spill response and contingency plans and executing the planned responses during an oil spill event.

The specific objectives of the study were to execute the following:

1) Identify and assess the environmentally sensitive areas, including shoreline type, biological resources and socio-economic features using GIS method.
2) Define the index of environmental sensitivity from different parameters that are suitable for the Gulf, based on an Environmental Sensitivity Index (ESI) ranking method and analysis.
3) Prepare thematic maps of priority sensitive areas for oil spill response planning in the Gulf.

## 1.3 Research Significance

The Environmental Sensitivity Index, originally proposed in 1978, has become a benchmark scheme for coastal managers, planners, and scientists in determining the effects of oil on their shorelines (Gundlach and Hayes, 1978). The shoreline type, biological resources, and socio-economic features are weighed to assess the influence of a particular degree of oil spill, and for better analysis of environmental sensitivity. The outcomes of this study can be used as a guide for a larger scale ESI map covering Saudi Arabia for oil spill response strategies.

## 1.4 Thesis Outline

The present research is divided into six chapters, including this introductory chapter, as summarized in Table 1.

Table 1. Thesis Outline

| Chapter | Description |
|---|---|
| 1 | General introduction about the background of the study, objectives and the research significance. |
| 2 | Literature review on environmental impact of oil spill, ESI mapping and GIS approach in this study. |
| 3 | Methodology and procedure to produce the ESI map and determine environmental sensitivity of the study area. |
| 4 | Contains the results of the study with comments. |
| 5 | Results of this study. |
| 6 | Conclusions of the study and recommendations for future work. |
| Appendices | Spatial raw data of ESI parameters, complete attribute table of socio-economic features and complete ESI map in all grid zones. |

# CHAPTER 2

# OIL SPILLS AND GIS MAPPING

## 2.1 Oil Spills and Environmental Impact

### 2.1.1 Oil Spill Fate in the Marine Environment

Any type of oil can contaminate the aquatic environment. Oil slicks may vary from crude oils to refined products of varying viscosity (pour point). The type of oil is one of the key factors that must be considered before planning any oil spill response. Oil spills can be accidentally released from offshore platforms and submarine pipelines, drilling rigs and wells, or oil transportation or distribution incidents. Also, intentional releases are a possible risk (e.g., the 1991 Gulf spill, as mentioned in Ch. 1). Spills will have different oil types, depending on the source of the spill.

When oil enters the marine environment it undergoes complex processes that disperse and degrade the oil and these processes are called weathering (Figure 1). Weathering processes include spreading, evaporation, dispersion, emulsification, dissolution, oxidation (including photo-oxidation), biodegradation, aggregation and sedimentation (Beyer, 2010). Spilled oil is weathered in different ways, e.g. natural dispersion of oil into the water can cause part of the oil to leave the sea surface, whereas other processes including evaporation or formation of water in oil emulsions can cause the oil to remain on the surface in a persistent form.

The persistence of the oil also influences the way an oil slick breaks up. In the case of light refined products, such as kerosene, the oil lacks persistence and tends to evaporate and dissipate quickly. But if the oil is persistent, as crude oils tend to be, the slick will break up and dissipate slowly. Thus, such spills usually require a clean-up response. Parameters such as density and viscosity affect the persistence of oil, so basically the higher the density and viscosity values are, the longer the break-up time of the oil spill slick.

Dissipation of oil does not occur immediately, and the time it takes depends on a series of factors. These factors include the amount and type of oil spilled, weather conditions and whether the oil stays at sea or if it is washed ashore.

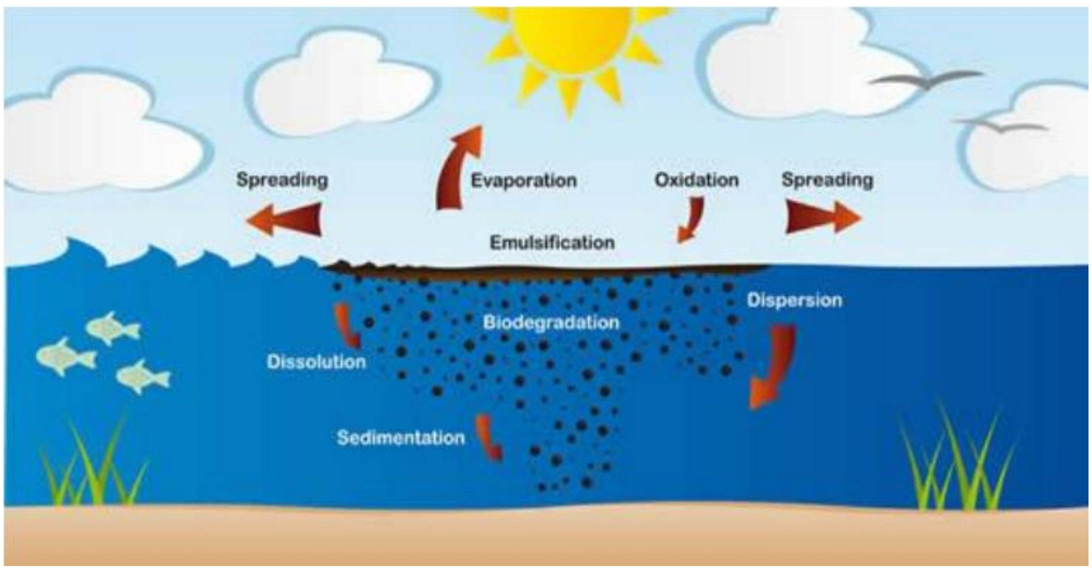



Figure 1. Main weathering processes in oil spill degradation
(ITOPF, 2011)

The spilled oil will come to shoreline under the influence of water current, wave action and tidal flow and remain in the shoreline and continue the weathering process. Therefore, oil spill contingency planning is required to protect the coastline and sensitive habitats before spilled oil reaches the shoreline, if possible.

### 2.1.2 Environmental Impacts of Oil Spills

Oil spills can have deleterious impacts on coastal ecosystems (Mendelssohn, et al. 2012) and economic activities such as harvest of fisheries or the tourism industry (Garza-Gil et al., 2006). Oil that remains on the water's surface as a slick can produce major impacts on organisms that are associated with the air-water interface such as sea birds and marine mammals. These deleterious impacts can derive from both physical and chemical effects of oil. For example, oil can coat the plumage and fur of birds and fur-bearing marine mammals. Ingestion of oil as well as loss of thermal insulation properties from the oiled feathers or fur can produce severe consequences to the animals. Unintentional inhalation of oil by aquatic, air-breathing organisms can produce respiratory complications. At the same time, dispersion of oil as droplets from surface slicks into the water column will lessen impacts to organisms at air-water interface, but enhance exposure to biota in the water column if the oil is not sufficiently diluted or occurs in very sensitive zone (Clayton, et al, 1993).

The effects of spilled oil on organisms may be either acute or chronic (Morales-Caselles, 2007) and depend on the type of the oil released. Benthic organisms, which are usually not impacted by oil in the emulsion form, may be affected by oil residues (tar balls) which are likely to settle on the sea bottom. Additionally, the impacts of oil spill will be greater if occurring near the coral, seagrass, salt marshes or mangrove area along the shoreline. Some studies on coastal areas heavily impacted by oil spills have reported the existence of significant long-term impacts on various organisms for many years after the visual signs of pollution (Villeneuve, 2007 and Joydas et al., 2011).

### 2.1.3 General Oil Spill Contingency Planning and Management

A successful contingency plan for oil spill response integrates the classification and mapping of coastal environments that will be seriously damaged by an oil spill so that the sensitive environments receive priority protection. The decision support system for oil spill response as proposed by Pourvakhshouri and Mansor (2003), includes environmental sensitivity mapping as one of the main components for simulation and planning. After there is an oil spill report, the oil responders track the oil spill using oil spill models and the ESI map as references for taking action in the field (Figure 2).

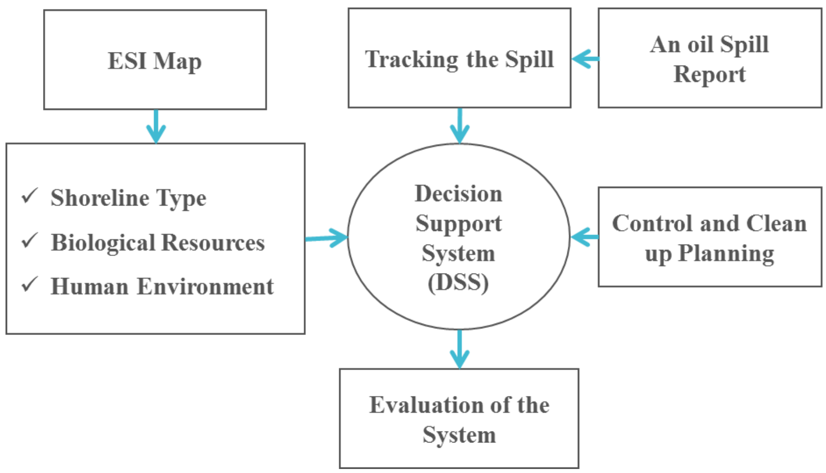



Figure 2. Decision support system for oil spill management planning (Pourvakhshouri and Mansor, 2003)

## 2.2 Environmental Sensitivity Index (ESI) Map

Environmental sensitivity mapping compiles information about shoreline type, biological resources or habitat, and human environment that has socio-economic values. The idea was originated in the mid-1970s when scientists with the National Oceanic and Atmospheric Administration (NOAA) in the USA and the US Coast Guard began to study and numerically classify the sensitivity of shorelines to oil spills (Figure 3).

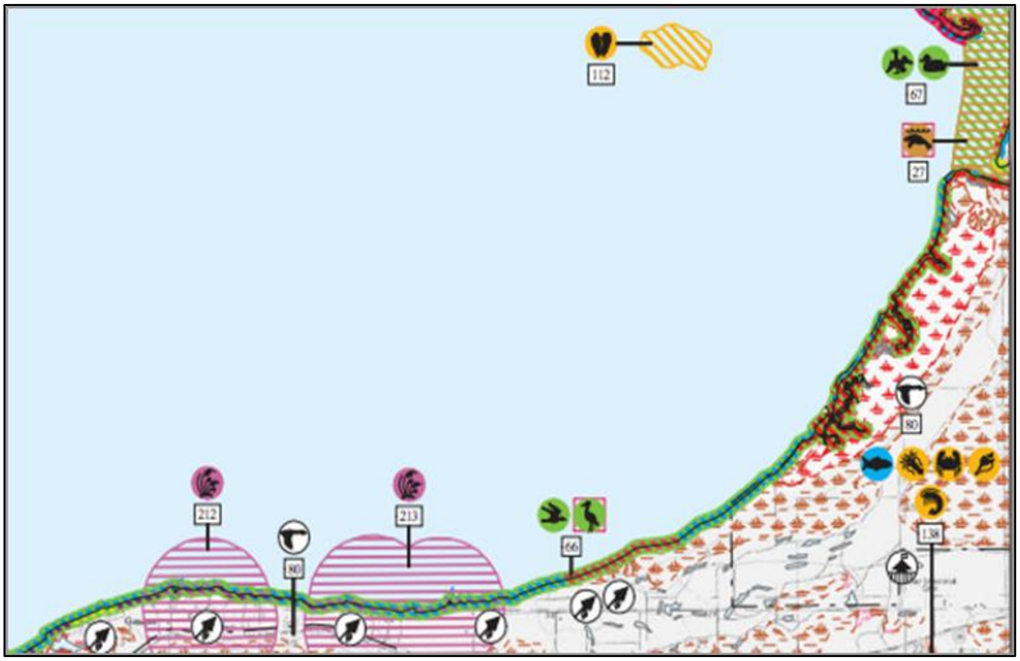


Figure 3. Thematic ESI Map with Sensitivity Parameters
(NOAA, 2003)

After 1989, sensitivity maps started considering the following three main spatial information: the original habitat sensitivity in certain classification scale, the local biological resources vulnerable to oil exposure, and vulnerable commercial, recreational and human subsistence resources (Jensen, et.al., 1998). This information is used in planning to create clean-up strategies before an accident occurs so that authorities are prepared to take remedial or mitigation actions in case of an oil spill. Therefore, protection and preparedness of oil spill responses are essential for coastal management and reducing the adverse impact of oil spills in coastal areas.

### 2.2.1 Shoreline Type

In coastal areas, certain shoreline types or habitats have a high likelihood of being directly oiled when the oil spill impacts and sticks to the shoreline (Inbar, 2007). It is recognized that the spilled oil's fate and effects are dependent on shoreline type, especially for clean-up methods that will be used (Hayes and Michel, 1997; Gundlach and Hayes, 1978). Many studies have adopted ESI for environmental sensitivity mapping for oil spill contingency planning or coastal management. Examples include studies of the New Zealand Coastline (Tortell, 1990), Shetland Island, UK (Khrisnan, 1995), United States Coastline (Jensen, et al., 1998), Ras-Mohammed coastal zone, Egypt (Abdel-Kader, et al., 1998).

The present ranking system for shoreline habitats is mostly developed for temperate and tropical zones with developed analyses and parameters. These include studies of the Rio Grande de Norte State coastal area, Argentina (de Castro, et. al, 2004); Amazon Coast, Brazil (Souza, et al. 2004); São Paulo State coastline, Brazil (Carmona, et al, 2006); Cardoso Island State Park, Brazil (Wieczorek, et al., 2007); United Arab Emirates Coast, UAE (Jensen et al., 2008) and Iranian Coastline, Iran (Nouri, et al., 2009).

Environmental sensitivity ranking for a particular shoreline type is the integration of the physical, social and biological character of the shoreline environment, not just the substrate type and grain size (Zirpolo, 2014). The key to the rankings is an understanding of the relationships among physical processes, substrate type, and associated biota, which produce specific geomorphic/ecological shoreline habitat types, and predictable patterns of spilled oil behavior, sediment transport patterns, and biological impacts (Michel, et al., 1978; Jensen, et al., 1998) and little seasonal change (Wieczorek, et al. 2007).

### 2.2.2 Biological Resources

Biological resources include ecosystems (habitat) that are sensitive to oil spills. In the environmental sensitivity method, the natural environment normally is classified into ecosystems (habitats). These include intertidal and subtidal regions; and six categories of biological resources include marine/terrestrial mammal, birds, reptiles and amphibians, fishes, and invertebrates (Jensen et al., 1998). Mapping the entire distribution of a large number of species potentially located in an area, and showing it on the environmental sensitivity map, may not be very helpful to responders setting spill protection priorities. It is more reliable to identify only the types of natural environment that tend to be sensitive to oil spills (Krupp and Abdulaziz, 2008).

The Gulf supports various coastal and marine habitats, including sensitive types including mangroves, coral reefs, and seagrass beds. The two major habitats in the Gulf coastal zone are intertidal and subtidal regions. Tidal flats are part of the intertidal region that occupies 30 - 40% of embayments of the coastline (Basson, et al., 1977). The tidal flats in the Gulf are characterized by a series of well-defined zones and include mangroves, salt marshes and sabkhas (Figure 4). The subtidal region found below the lower intertidal zone that includes seagrass beds, coral reef, and common condition such as sandy, rocky and muddy area (Figure 4).

Seagrass beds can be described in terms of their term of composition of plants. They occur in subtidal areas, principally in shallow coastal areas. The seagrass species identified in the Gulf coast include *Halodule uninervis, Halophila stipulacea and H. ovalis* (Saudi Aramco, 2014). The amount of seagrass cover was observed. The seagrass beds are the most important communities in the overall biological economy of the Gulf

(Basson, et al., 1977), providing habitat for a wide variety of both adult and developing juvenile organisms.

(a) Sabkha

(b) Mangrove

(c) Salt Marshes

(d) Coral Reef

(e) Seagrass Beds

(f) Muddy Area

Figure 4. Intertidal Habitats (a, b, c) and Subtidal Habitats (d, e, f)
(Saudi Aramco, 2014)

Salt marshes areas are a dominant habitat of the intertidal area, which is located below the mean high water level and above the mean sea level, and then flooded according to local tidal periodicities (Belluco, et al, 2006). The vegetation in this ecosystem are known as halophytes - kinds of plants that can live and survive under saline conditions.

Mangrove refers to the complex plant community which encompasses the marine and land habitats. The habitat harbors a myriad organism that includes snails, oysters and crabs. It serves as spawning and nursery grounds of fishes, including many commercially important ones. Some of the species hence are directly or indirectly a major resource (Koenig, et al., 2007). The extensive root system of the mangrove plants keeps the substrate firm and thereby mangroves serve to mitigate coastal erosion (Bell and Lovelock, 2013).

Coral reefs are an integral part of the coastal zone ecology in tropical and subtropical areas (Gundlach and Hayes, 1978). The corals are sometimes exposed or nearly at the water surface during low tides. Shallow coral reefs may be severely damaged when subjected to oil pollution. The offshore island, such as Karan, Kurayn, Jana and Jurayd Island, are surrounded by rich corals forming the reef ecosystem (Marine Atlas, 2014).

Coral reef oiling will result in decreases in coral cover, decrease in coral fecundity, decrease in coral reproductive tissues and survival of coral larvae (Rogers, 1990; Guzman et al., 1991). It is not recommended to engage in a type of cleaning-up process on corals unless there is heavy oiling, as any cleaning-up operation could damage the coral reefs more than the oil itself and the appropriate spill-response is to prevent oil from reaching the coral area as much as possible (Guzman and Holst, 1993).Therefore, mapping of coral habitat for environmental sensitivity is essential to know which area may require the type of response that will alter the pathway of an oil spill.

### 2.2.3 Socio-Economic Features

Socio-economic features of interest of interest include the objects or locations that have important value to people and economic development. The features shown on the map are those that would either be impacted by oil spill or provide access to the clean-up operations (Ornitz, and Champ, 2002). Sensitive socio-economic features to be mapped should include important areas that may be directly injured by oiling or areas that may suffer economically. These include, for example, places that would experience an interruption of use if they were oiled; and areas that may be valuable in the event of a spill for access or staging activities.

Socio-economic features are divided into four major components, as follows: (1) resource extraction sites, such as desalination plants, aquaculture sites, locations of subsistence and commercial fisheries, mineral extraction sites, and surface-water intakes; (2) management or protected areas, such as national parks, marine sanctuaries, national wildlife refuges, preserves, and hunting reserves; (3) archaeological and historical locations; and (4) high-use recreational and shoreline access areas, such as boat ramps, marinas, recreational beaches, and sport-fishing and diving areas (IPICEA, 2012).

## 2.3 Geographic Information System (GIS) Mapping

Geographic Information Systems (GIS) are computerized systems for data storage, spatial and temporal analysis of data, and display of geographically referenced data. GIS has valuable application in the field of marine coastal management. Environmental sensitivity maps in GIS based have many features that make the maps useful to spill response teams. This type of map is created using the GIS method in order to present regional maps with data on shoreline type, the natural and human environment in certain areas, as well as information inside (meta-data).

### 2.3.1 GIS Roles and Functions

GIS has the utility to combine analyses of different spatial data with various congruent data analyses. Many studies have applied GIS for different aspects in environmental sensitivity mapping (See Table 2). Using a GIS-based approach to develop environmental sensitivity maps offers several advantages, such as storing and managing the information (images, statistics, etc.), and thus easily creating and updating the sensitivity maps, producing maps at suitable scales, and with relevant layers of information, and in various formats (paper, PDF, interactive maps using the Internet) and sharing and communicating the information (IPICEA, 2012).

Table 2. Role of GIS in Environmental Sensitivity (ES) Mapping

| **GIS role in ESI mapping** | **Sources** |
|---|---|
| Environmental sensitivity mapping for oil spill contingency plan | Tortell, 1990; Khrisnan, 1995; Abdel-Kader, et al, 1998; Jensen, et al., 1998; El-Raey, et al.; 1996; Souza, et al., 2004; de Castro, et. al, 2004; Adler & Inbar, 2007; Percy, et al., 2007; Jensen, et al., 2008; Furlan, et al., 2011; |
| Generation of environmental sensitivity index information and database | Beisl, et al., 2003; Souza, et al., 2009; Wieczorek, et al., 2007; Nouri, et al., 2009 |
| Environment sensitivity mapping and vulnerability modeling | Carmona, et al., 2006, de Castro, et al. 2006; Pincinato, et al. 2009; |
| Oil spill vulnerability assessment and integrating parameter analysis | Szlafsztein, et al., 2007; Castanedo, S. et al., 2009; |
| Environmental sensitivity data management and sharing using Web-GIS | Nxumalo, et al. 2013 |

### 2.3.2 Spatial Data Model (Vector/Raster)

Data about the real world should be defined and organized into a consistent digital data set from which various information can be gathered. The process of defining and organizing data is called data modeling and the logical organization of data according to a scheme is called data model (Canter, 2004).

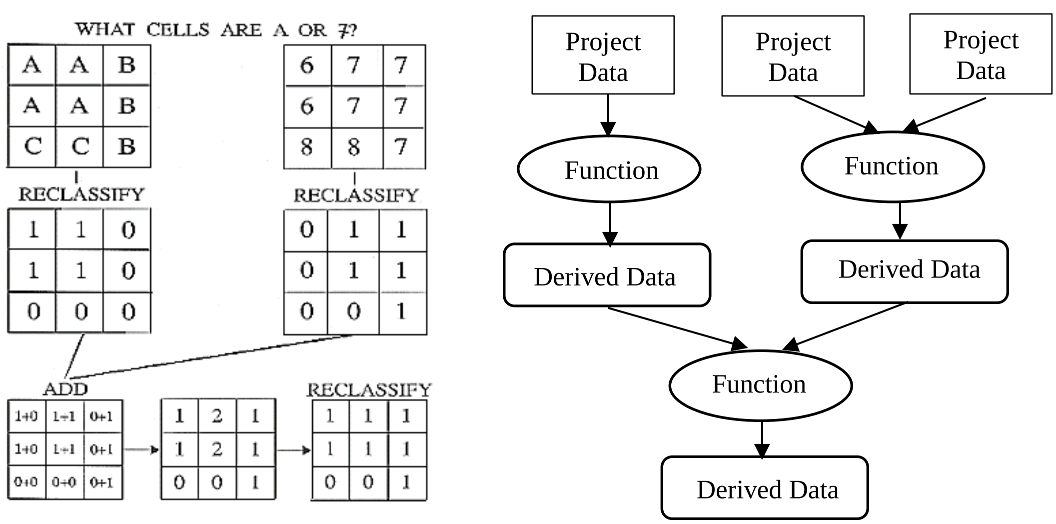
There are two fundamentally different methods for describing spatial reality: field approach and object approach (Canters, 2004). Field approach is used mostly for describing data of continuous spatial variation (i.e. elevation), and in which measured values (attributes) for irregular setting (location) are commonly transformed into a regular grid by means of an interpolation method. Object approach is used to describe the parameters that are characterized by discrete spatial variation. Data are normally represented in the object approach by means of points, lines and areas (polygons). Two commonly used data models are the vector data and the raster data.

In vector data, objects are represented by two main components: a set of thematic attributes that are linked to a specific object class through a unique identification code, normally referred as object ID and geometry building elements. In the raster data model, spatial reality is represented by means of regular grid that covers the whole study area. Each cell of the raster grid receives only one value that describes the thematic content of that cell. Raster is normally defined by its origin (x,y coordinates), its resolution (the pixel size), and its dimensions (number of rows and number of columns). Since each raster cell can only have one attribute value, combining different raster leads to the typical layer structure that characterizes the GIS. Raster model makes it computationally easy to combine different themes using various operations (overlay analysis).

### 2.3.3 Spatial Analysis using ArcGIS

Spatial analysis is one feature of the ArcGIS package. This technique is used for analyzing the spatial data, in the form of either vector or raster data. It accommodates operations research, spatial interaction, and geostatistical analysis to develop optimal problem solutions. Spatial data sets in various data types may be used. In spatial analysis, the spatial relations between different themes are studied by applying simple arithmetic operations or methods (Canters, 2004).

There are two methods or models for spatial analysis that could be applied in raster data analysis. One of the methods for spatial analysis is called Map Algebra (Figure 7a). Map algebra is based on the definition of a large set of operations, which are applied to one or more input layers to produce a new layer. This enables the solution of very complex spatial problems by combining different operations (Canters, 2004).Another method for spatial analysis is cartographic modeling. Cartographic modeling is the logical combination of different operations in such a way that the output of one operation is the input of another one (Figure 7b). Cartographic models commonly contain a flowchart that shows the procedure and the order, in which different input maps are combined to give the final deductive map.




(a) Basic Idea of Map Algebra (b) Basic Cartographic Modeling

Figure 5. Raster Data Modelling using Spatial Analysis in ArcGIS

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

The National Oceanic and Atmospheric Administration (NOAA) of the US issued the Environmental Sensitivity Index Guidelines that define the ranking standard of scoring levels of shoreline type and biological resources as proposed in a study from Gundlach and Hayes (1978). After that, collaboration between International Petroleum Industry Environmental Conservation Association (IPICEA), International Maritime Organization (IMO), and International Association of Oil and Gas Producers (IOGP) later issued a comprehensive guideline on sensitivity mapping for oil spill responses (IPICEA, 2012). This guideline provides the three parameters that should be included for ESI mapping. It also explains the parameters criteria to produce thematic maps that contain information about shoreline type classification according to a scale relating to sensitivity, natural persistence of oil, and ease of clean-up; biological resources including oil-sensitive habitats which are used by oil-sensitive species or are themselves sensitive to oil spills; and, socio-economic features including specific feature that are impacted when oil spills occur.

The ESI mapping guidelines from NOAA (2004) and IPICEA (2012) has been followed in this study. These include shoreline-type classification, biological resources, and socio-economic features. This study formulated a cumulative sensitivity measure from the three parameters above and made a thematic map of environmental sensitivity to oil spills allowing the prioritizing of areas that should be protected. Note that the previous ESI parameters in NOAA guidelines were focused only on the shoreline type. This cumulative sensitivity technique as used here could help the policy decision makers or oil spill responders to determine the sensitive area as holistic parameters for shaping oil spill response strategies at national or regional levels.

The scheme methodology in this study thus includes determining the study area (geographic reach) of mapping and analysis, gathering data for all parameters, pre-processing data, storing data, processing spatial data (vector and raster data), making visualization of data output, and preparing the final maps that include the thematic ESI map and priority sensitivity areas for oil spill response in the Gulf (Figure 6).

In this study, Geographic Information System (GIS) is used to elaborate the composite sensitivity index with different parameters. The resulting thematic ESI map has been developed to identify the locations of sensitive parameters for oil spill response. After that, spatial analysis in GIS was used to identify the prioritized sensitive areas that require special protections in case of oil spills in the Gulf.

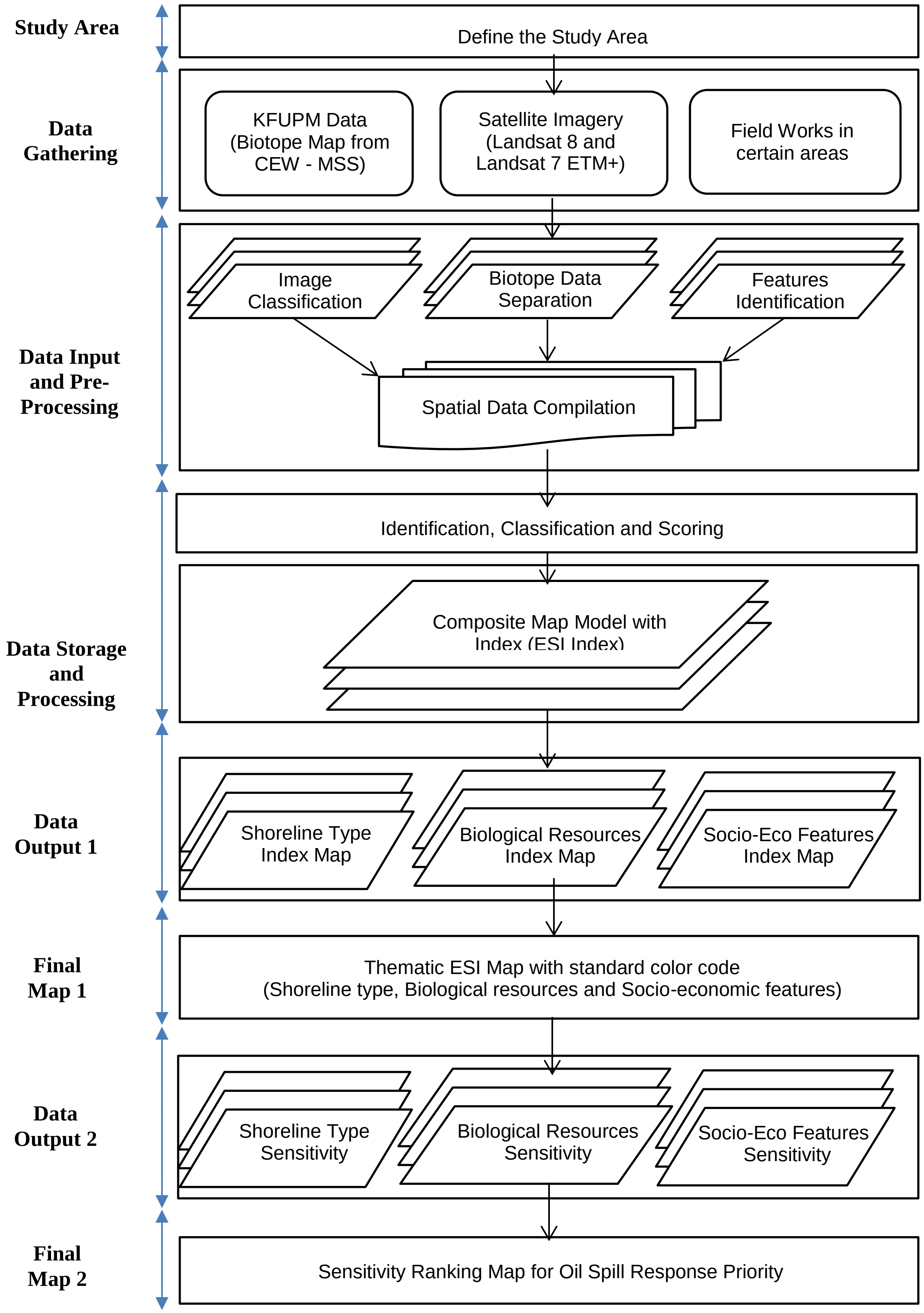



Figure 6. Scheme of methodology for preparing ESI and sensitivity ranking map

## 3.2 Define the Study Area

The Gulf is characterized by shallow water, with depths varying around 30-50 m in the Western Arabian Gulf area. It is characterized by many shallow bays, commonly with water depths less than 8 m. This study prepared an ESI sensitivity ranking map of the coast line of Saudi Arabia from Khafji in the north to Dammam in the south (Figure 7). This includes a shoreline of approximately 452.209 km over which classifications of shoreline type, biological resources, and socio-economic activities were mapped. These areas also have several oil-related activities both in the near shore and offshore areas. In addition to that, several crude oil pipelines are located in the coastal areas, linking the offshore platforms with onshore facilities. Ras Tanura, for example, is an area which has an oil terminal, oil refinery and other oil-related development activities. Another important aspect considered is that areas from Safaniyah to Abu Ali, still shows residual oil in the shoreline at some locations, the occurrences of which are related to the 1991 oil spill (de Mora, et al., 2010).

The geographic area studied (layout coordinates) are as given below:

| | |
|---|---|
| Coordinate System | : WGS_1984_UTM_Zone_39N |
| Projection | : Transverse Mercator |
| Latitude | : 26°15’35” - 28°15’45”N |
| Longitude | : 48°28’15”–50°15’05”E |
| Datum | : D_WGS_1984 |

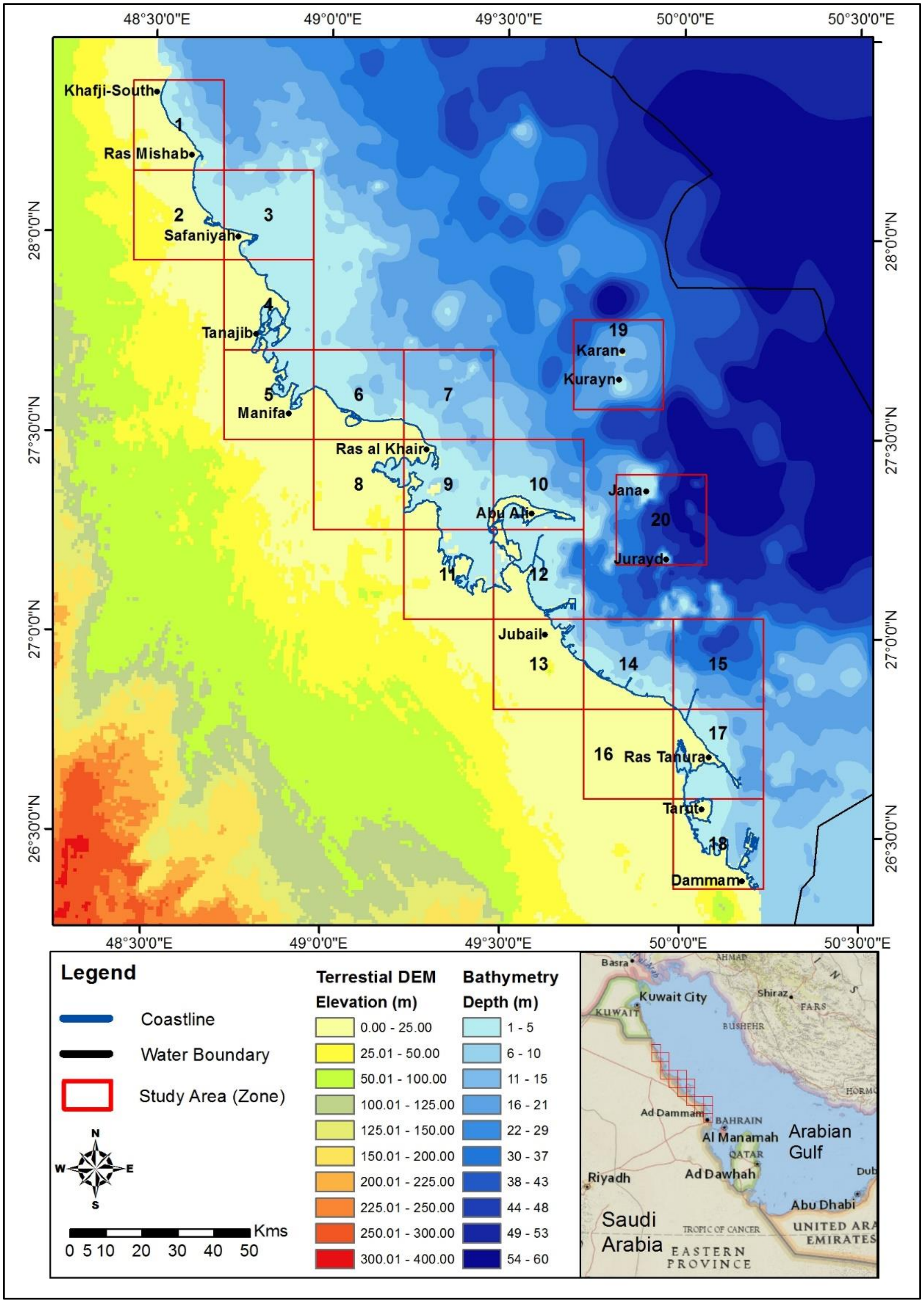



Figure 7. Study Area in the Western Arabian Gulf with Digital Elevation Model (DEM) in terrestrial area and water depth (bathymetry)

The study area is divided into 20 grids, each consisting of approximately 25x25 km square, for providing analysis of appropriate scale for map visualization for environmental sensitivity mapping. These grids have different geological settings and conditions in terms of environmental sensitivity parameters, and cover along the shoreline and biological resources near the coastline and oil-related activities. Therefore, the grids make appropriate study areas for the assessment and zoning of environmental sensitivity using the resulting maps. Proper response to oil spill incidents is important and these maps are useful with respect to maintaining sustainable development in this coastal area.

## 3.3 Data Gathering and Processing

Data collection on environmental sensitivity was conducted by field work, literature review, and biotope map reporting available from the Marine Studies Section, Center for Environment & Water, KFUPM, and by the analysis of remote sensing data for shoreline types and some marine habitats. The classification is primarily based on environmental sensitivity of the marine habitat or ecosystem to oil spills. For example, ecosystems including mangroves, salt-marshes, and tidal flats are known to be most sensitive and show the long-lasting impact to oiling, and was thus given priority for clean-up processing (Krupp and Abdulaziz, 2008). The length of this type of shoreline was generated by field inspection and remote sensing employing data digitizing with image analysis to separate water and land using Landsat Imagery 8 Band 1.

The database information on the natural environment was obtained from biotope mapping and reporting from the Marine Studies Section, Center of Environment and

Water (CEW), Research Institute, KFUPM (KFUPM, 2010) and the Marine Atlas of the Western Arabian Gulf (Saudi Aramco, 2014). The information was plotted as vector data with polygon format and was displayed with different color codes and symbols.

The information about socio-economic features was obtained from point of interest (POI) information in google map. Then, selected data were plotted in the maps with brief descriptions provided as well. The following features were plotted, based on the classification of socio-economic features that may be directly impacted by oiling, or specific areas that may suffer economically, as well as areas that may be valuable in the event of a spill for access as required by oil spill response and contingency planning.

The data set from different disciplines are needed to produce a typical ESI map. However, one can overcome the initial lack of a particular kind of data by consulting different sources of information and carefully studying the existing literature. The data used in the present research are spatial data. Different kinds of digital data were available for performing the ESI mapping for the selected Gulf area. The data included the basic data set to start ESI mapping. Although aerial photographs are a basic component in the original procedure, they were replaced here by Landsat 7 ETM+ satellite imagery Level 1 available from http://earthexplorer.usgs.gov/ that are available on a free access basis for registered users in certain areas of availability.

## 3.4 ESI Map Preparation

### 3.4.1 Shoreline Type Classification

The shoreline type information is the most important component of any ESI map. The final sensitivity ranking of a particular shoreline segment is the integration of the three main factors: shoreline exposure and substrate or biological productivity. In the procedure developed by NOAA (2004), the final shoreline habitat ranking is digitized into GIS maps with temporal attributes which enable further updates. Satellite imagery data assisted the shoreline digitalizing using image processing ENVI 5.0 and ArcGIS 10.2, with different types of image processing analyses as processed below (Figure 8).

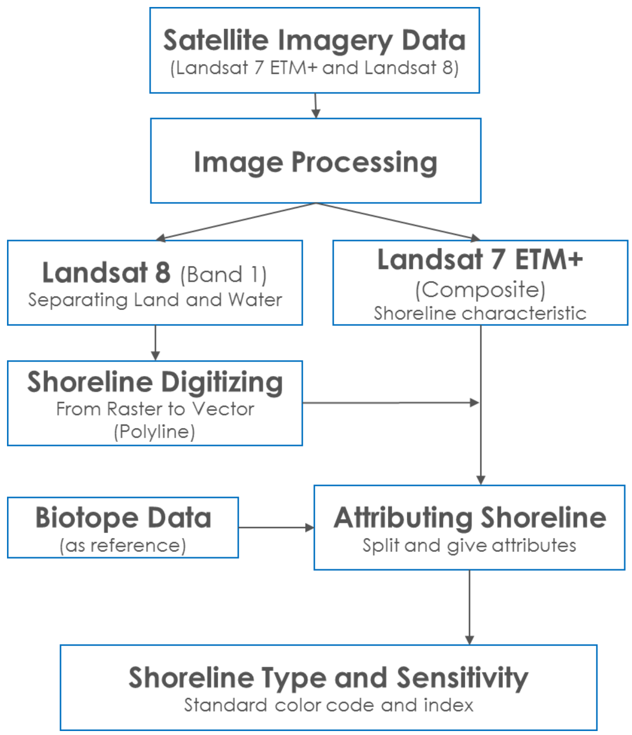



Figure 8. Shoreline type classification and processing using satellite imagery

The key point in the present research is the use of GIS for developing the ranking itself. That was done using a simple cartographic model, in which different factor maps were used as input layers and by combining these factor maps using overlay analysis, the final output was the shoreline habitats classified according to their sensitivity. Following are the main steps in performing the shoreline sensitivity classification process:

1. Data Preparation

Some of the needed maps were provided in a GIS format. These included the contour map obtained from the USGS Digital Elevation Model (DEM) with raster format, which contains the elevation value in terrestrial area and satellite imagery level 1 data. Following are the steps used for creating layer basic maps for the spatial analysis:

a. DEM from USGS is used to determine the elevation in the shoreline and Geo-TIFF format of satellite imagery Landsat 7 ETM+ to define shoreline condition and Landsat 8 with band 1 (Coastal) to separate land and water.
b. Digitizing the shoreline with base-map that have already been prepared.
c. During digitizing the shoreline, a unique identification code for each object on the map has been given to enable the further assignment of more attributes using line split in GIS editor.
d. A separate editing phase of digitizing errors has been carried out using the editing features in ArGIS 10.2 and others.
e. Resultant vector maps were linked to the attribute tables through the identification code and map layers were converted to shape file format (Figure 11).

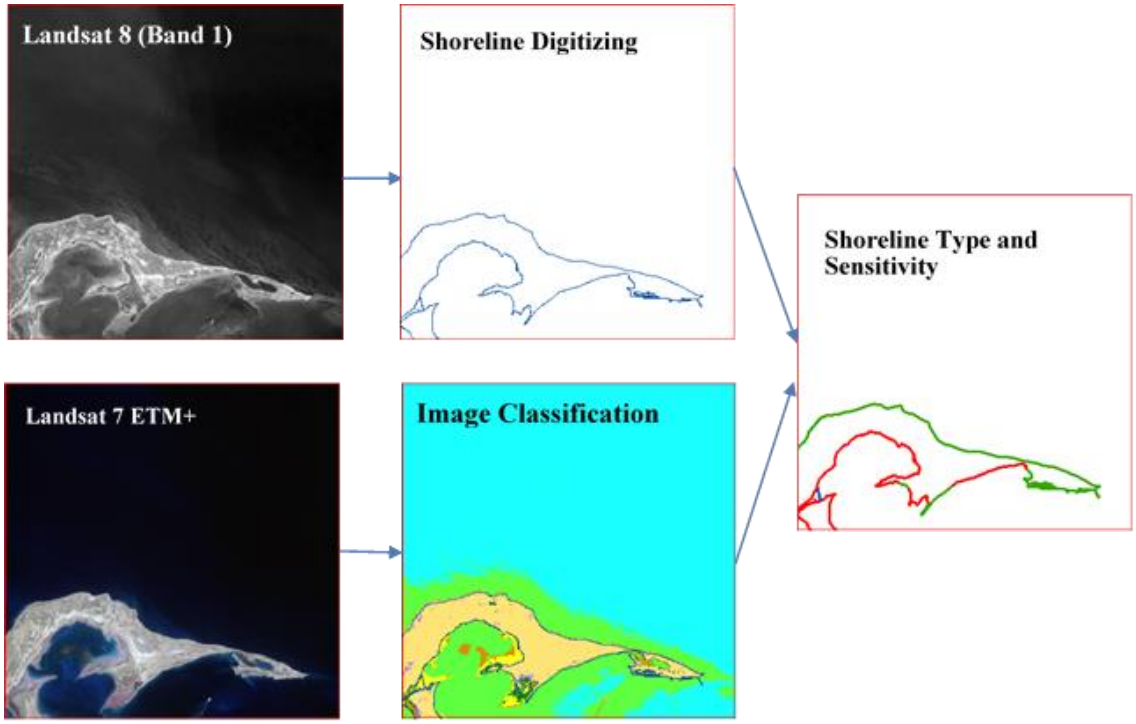



Figure 9. Satellite imagery processing and digitizing to vector data (shapefile)

In order to achieve a correct overlay analysis; all the input layers should have the same coordinate system. ArcGIS Toolbox 'define projection' was used for all maps. The data are assigned the same coordinate system with the following parameters:

Projection: UTM

Units: Meters

Zone: 39N

Datum: D_WGS_1984

Spheroid: WGS_1984

Another important step is the conversion of each factor map from vector to raster, as the overlay analysis will take place in a raster environment. The grid cell dimension (resolution) selected for all factor maps was a value of 5 m. This value was found to be the most convenient in two ways: it is not a very large value which could cause data loss, and at the same time it is not a very small resolution which could result in huge files that commonly prove very difficult to be handled and processed.

2. Region of Interest (ROI) delineation

The target area for performing the sensitivity analysis is the shoreline-type classification. It was digitized from the satellite image as a line map. In the ESI guideline (NOAA, 2004), the line segments are assigned the ESI value by the geologist in the field. In the other guideline (IPICEA, 2012), the ESI can be simplified into 5 classes rather than the customary 10 rank levels of the environmental sensitivity. These conditions cover the possibility of having the same segment with different ESI values due to the landward or seaward change in habitat. In the present research, however, a buffer zone of 100 m was created around the shoreline and used as the ROI for doing the sensitivity analysis. It was found be easier or even more correct to do spatial overlay on a raster created from an area in the buffer zone, than to have it converted from a line feature.

Another overlay procedure that could be used in doing the calculation is the weighted overlay process. This approach could not be used in the present study, as one needs to decide about the weights of the factors and this needs very detailed work on the relation between the sensitivity and each affecting factor, which was beyond the scope of the study. The result of the overlay process is considered to be the local sensitivity index of the shoreline habitats. This map was consequently a subject for applying other considerations, i.e. those affecting the sensitivity locally due to the conditions found in the study area. The sensitivity index was then compared with the ones produced by NOAA (2004) and IPICEA (2012) guidelines.

### 3.4.2 Biological Resources Compilation

Producing an ESI map involves gathering biological data from a variety of sources, compiling it into maps, entering the data into GIS and linking those data with attributes that are important regarding oil spills. The key biological resources of the area are those that are most likely at risk in the event of an oil spill. Those are depicted on the maps. In this study, biological resources compiled for the analysis were the habitat or ecosystem near to the shoreline, such as, mangrove, salt marshes, seagrass beds, and coral head or reef. The ecosystem or habitat with image classification components representing biological resources in ESI mapping, the spatial component, in which different biological resources are digitized on the base map as points and polygons; were created in a simple data forms using Microsoft Excel.

Satellite imagery from Landsat 7 ETM+ was classified with two main methods, unsupervised and supervised classification with biotope data as references (Figure 10). Landsat 7 ETM+ imagery was used after its generated dark object subtraction and radiometric correction using ENVI 5.0 software. Dark object subtraction was used to remove the path of the radiance from satellite, in order to get the value of reflectance and achieve enhancement of the image classification. Radiometric correction was used to define the spectral of the reflectance to identify the material, but the problem was the satellite-measured radiance. Converting the radiance to spectral reflectance enables using radiometric response function based on the meta-data of the imagery.

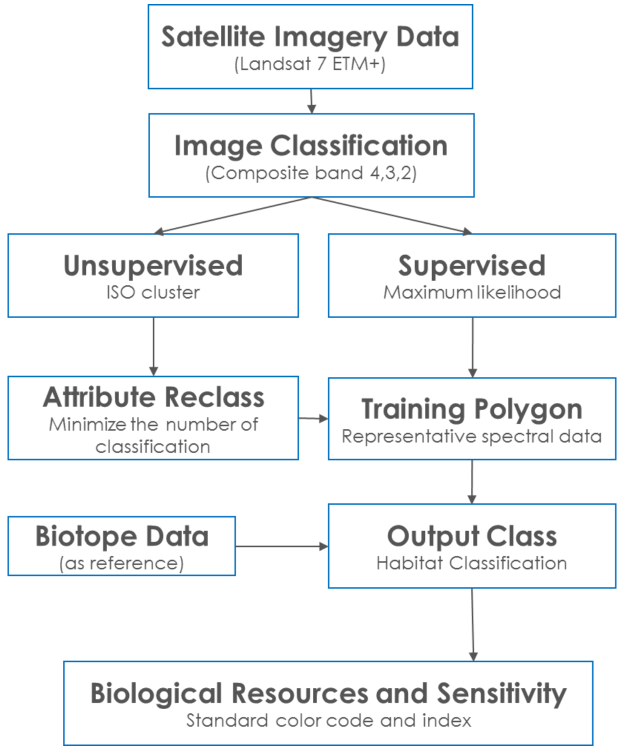



Figure 10. Biological resources classification and processing using satellite imagery

In unsupervised classification in ArcGIS, the image classification toolbar was used to generate the iso-cluster of the image. The image was classified based on the different of reflectance in composite band 4 3 2 (Near Infra-Red Composition), to define the health of vegetation in an area. After that, data are reclassified using re-class analysis to different ROI. In supervised classification, maximum likelihood analysis is used to classify the different ROI with training polygon. Training polygon represented the criteria with different reflectance of the image and classified with biotope map as references. After biological resources (habitats) were classified, it defined the color and different attributes with the index or sensitivity scoring.

### 3.4.3 Socio-economic Feature Identification

Socio-economic features could be identified as the places that were important to people in the study area or were a Point of Interest (POI) in Google Map, such as airport, park, beach, school, market, port, etc. However, there were several point locations that could not be found in the Google Map database, such as discharge locations from agricultural and municipality sources, or fish landing sites, or even oil-related activities locations such as refinery plants, GOSPs, etc.

Socio-economic features identified in study area were the features that were close to near shore and that would be impacted during oil spill occurrences. Most of the socio-economic features were depicted on the ESI map by point symbols such as recreational areas, water supply/desalination plants, parks, beaches, harbors, etc. While management areas were drawn as polygons, such as industrial areas, municipality sites, etc. These features were also assigned a feature attributes and feature symbols (Figure 11). The point features are identified from Google Map as general coordinate location and several spatial data from KFUPM, and plotted in ArcGIS 10.2, while the polygonal features were derived from the land-use map of the study area as the result of imagery classification.

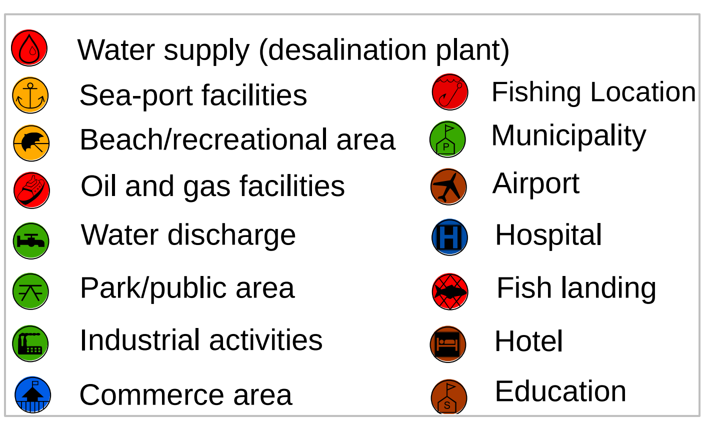



Figure 11. Socio-economic features symbol for point location

The socio-economic features were mostly depicted by an icon, but without color code. This icon was placed on the place where the resource is located. There are standard icons used for the point features, while for polygonal features one has to define the color and patterns. In this study, an appropriate template of colors was chosen to define the characteristic and sensitivity score according to the attribute assigned.

## 3.5 ESI Map Ranking Analysis

### 3.5.1 Spatial Data Analysis

Assessment of the selected parameter is the first step required to make an objective assessment for environmental sensitivity analysis. A set of data of biotope mapping is used to evaluate the degree of sensitivity of shoreline type, and biological resources in the study area. An assessment parameter system was set up according to the following principles. The selected parameters can reflect the different type of shoreline and biological resources that have different degree of sensitivity scores.

Furthermore, the data of parameters are available for the establishment and operation of spatial distribution analysis. Through classification into the database of ecological environment, the key environmental sensitivity parameters reflect the sensitivity of ecosystem in the study area. It has relations with oil spill impact and contingency plan, and is selected as assessment parameters and classified into three main parameters including shoreline type, biological resources and socio-economic features as shown in Table 3. Then, spatial analysis of each parameter was conducted with Kernel Density Analysis in ArcGIS Toolbox. This generated and calculated the center of sensitivity of each parameter with a different score given as re-class analysis.

Table 3. The parameter attribute of environmental sensitivity index

| Parameters | Attribute | References | ESI Score |
|---|---|---|---|
| Shoreline Type | Solid man-made structure | (NOAA, 2012) | 1 |
| | Rocky-shore | | 2 |
| | Sand/beach | | 3 |
| | Muddy-shore | | 4 |
| | Vegetated (marsh/mangrove) | | 5 |
| Biological Resources | Submerged plant (seagrass) | (IPICEA, 2012) | 3 |
| | Coral/hard bottom reef | | 4 |
| | Sub-tidal plant (salt marsh) | | 4 |
| | Sub-tidal plant (mangrove) | | 5 |
| Socio-Economic Features | Airport | (IPICEA, 2012) | 1 |
| | Hotel | | 1 |
| | Educational Sites | | 1 |
| | Commerce area | | 2 |
| | Hospital | | 2 |
| | Water discharge | | 3 |
| | Park | | 3 |
| | Industrial area | | 3 |
| | Municipality | | 3 |
| | Seaport Facilities | | 4 |
| | Beach | | 4 |
| | Water supply | | 5 |
| | Oil and gas facilities | | 5 |
| | Fish Landing | | 5 |

### 3.5.2 Ranking Environmental Sensitivity Area

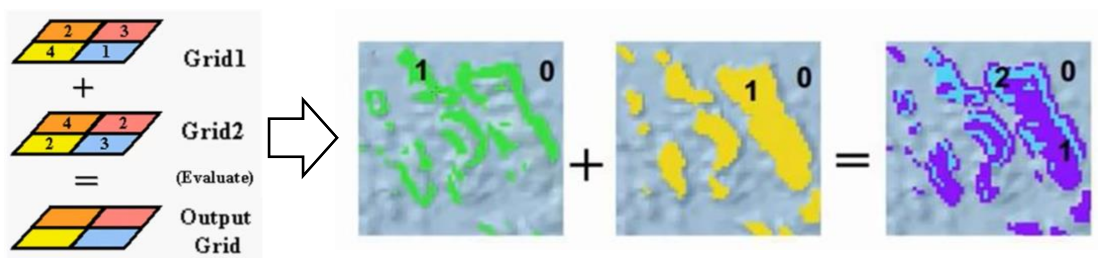
The assessment of environmental sensitivity was a process of spatial overlay analysis in practice, in which spatial overlay calculation was performed on the raster layers of grading, thus mapping each assessment indicator with different environmental sensitivity score. Before the composite index of environmental sensitivity could be calculated, the numerical or categorical data of each parameter were classified and simplified into five levels, i.e., non-sensitivity, low sensitivity, moderate sensitivity, high sensitivity, or extreme sensitivity, based on relevant international grading standards from NOAA. These corresponded to the values of 1, 2, 3, 4 and 5.

Sensitivity area is an overlay of the sensitivity area map. Sensitivity area to the oil spill component has been generated with the classification of the sensitivity area with binary analysis that excludes the non-sensitive area (non-sensitive area= 0 and sensitive area= 1). Most locations of this study area are sensitive to oil spills, but the mapping has a different condition for each location, as described above.

The grading or ranking resulting from binary analysis corresponding to each level above was assigned to the value of 1, 2, and 3. In this study, square grid cells with the size of 25 km2 were used for assessment units as consideration of the amount of computation necessary and avoiding information loss or redundancy. The value of each indicator was determined for each assessment unit by geo-spatial quantification of the indicator and translation into the grading result with kernel density methods.

Spatial analysis with map algebra in ArcGIS generated the binary result for each parameter and overlaid it to define the priority of the sensitivity area (Figure 12). Areas that were given three sensitive parameters were assigned as 3 (1+1+1) and became 1st priority for protection, and the areas that were given two sensitive parameters were assigned as 2 (1+1) for 2nd priority of protection. The other areas given one parameter were 3rd priority for protection. This analysis includes the shoreline type sensitive area, biological sensitive area, and socio-economic sensitive area. The color code has been given with red as the first priority, orange as second priority and yellow as third priority. This ranking priority was applicable for the general use in strategic planning or oil spill preparedness, for policy decision makers as well as oil spill responders to assess the condition and manage operations in the field (IPICEA, 2012). Spill incidents are tracked using oil-spill modeling.

Assessment parameters and the ranking value assigned were derived from the spatial analysis. Due to the different data sources of the indicators, the values of the parameters for each assessment unit were obtained through rasterizing, binary analysis, and spatial interpolation with ArcGIS platform, and projected onto a unified geographic coordinate frame in the study area.




(a) Raster Overlay (b) Ranking Sensitivity with Binary Methods (Zirpolo, 2014)

Figure 12. Spatial Analysis with raster data to determine the ranking protection of cumulative environmental sensitivity parameters

# CHAPTER 4

# RESULTS

## 4.1 ESI Map Layout and Parameters

The ESI map was prepared for the three main components or parameters. All the parameters were shown on one map that represents the ESI map of the study area. The final layout was created as an A4 size map using ArcGIS layout-viewer, which enables the production of the same map in larger sizes when needed. The grid zones of the study area assisted in allowing the certain area of interest with clear visualization and interpretation. All of the ESI maps for every grid zone appear in Appendix B.

### 4.1.1 Shoreline Type

The ESI map for shoreline type classification shows five classes of sensitivity over two different habitats (salt marshes and mangrove) and three substrate types (rocky, muddy and sandy). The higher the ESI score, the more vulnerable the shoreline type is or more difficult would be the clean-up process (Saenger, 1994; Beisl et al., 2003; Fingas, 2012).

Shoreline type has been identified in the shoreline that has been drawn in the map and the characteristic followed that condition. Shoreline type with solid man-made structure has been identified as concrete walls or rip-rap (permanent structural cover of rock that is used for stabilization or as wave breakers). This shoreline type has low sensitivity and is defined with brown or dark color. Rocky-shore has been identified as dominant rocky area in the shoreline with blue color. Sand/beach shoreline type has been identified as sandy/beach areas in estuary, exposed during low tide and these are shown with green color. Muddy-shore has been identified as muddy areas in tidal flat areas. This shoreline type is shown with yellow color. The vegetated shoreline type has been identified as salt marshes and mangrove that has high sensitivity to oil spill. This shoreline type was assigned with red color. The color code is more likely or characterized as standard from NOAA and IPICEA, and is shown clearly in the legend of the map (Figure 13).

The shoreline types in Khafji area showed moderate sensitivity (Grid 1). It has around 12.1 km length of vegetated shoreline with salt marshes, 11,1 km of rocky-shore and 1,7 km of sandy-shore. This area typically has medium sensitive shoreline types. While, in Ras Mishab, the shoreline type is dominated by sandy-shore of around 3,6 km length.

In Safaniyah area (Grids 2 and 3), the shoreline type is dominantly sandy-shore, rocky-shore and several vegetated shoreline types. Safaniyah is the open embayment that receives many tidal or wave activities. The shoreline type changed in Tanajib area that has more dispersed shoreline type. Vegetated shoreline type with several tidal flat areas, made salt marshes growth common in this area. Some of the area in Tanajib was classified with the muddy-shore and associated with vegetated shoreline.

The shoreline from Tanajib to Manifa (Grids 4 and 5) can be classified as sensitive. It is muddy- and vegetated shoreline of around 42.1 km length. Manifa (Grid 5) has highly sensitive shoreline type with sparse salt marshes that have a flat shoreline condition.

In Ras Al-Khair (Grids 6 and 7), the shoreline type is sandy--until closed embayment--that is mostly dominated by vegetated shoreline with salt marshes (Grid 8). This vegetated shoreline type dominates till Abu-Ali-Island (Grids 9 and 11) and is sensitive to oil spill. In the northern part of Abu Ali Island (Grid 10), shoreline type is identified as sandy-shore. Still, in the southern part of Abu Ali Island, most of the shoreline type is vegetated with salt marshes.

In northern Jubail (Grid 12), shoreline type is identified as sandy-shore and rocky-shore, near the Jubail sea-port. This shoreline type is sandy-shore and rocky-shore up to Ras Tanura area (Grids 13, 14, 15, 17). There was no shoreline in the grid 16. There is a park in Ras Tanura that has a shoreline type identified as man-made structure or rip rap.

In the southern-part of Ras Tanura area (Grid 17), mostly the shoreline type is dominated with vegetated shoreline and muddy-shore. This shoreline area is covered with sparse salt-marshes and mangrove. The most variable shoreline type occurs from Tarut Island to Dammam (Grid 18). The shoreline type is mixed from mostly vegetated in Tarut Island with mangrove area to sandy-shore, muddy-shore, and rocky-shore and solid man made structure in the Dammam Seaport.

In the offshore islands, most of the shoreline type is identified as vegetated area and sandy-shore. In Karan Island (Grid 19), the shoreline type is sandy-shore and vegetated shoreline with salt marshes, but, in Kurayn Island it is completely vegetated with salt marshes. Jana and Jurayd Island (Grid 20) also have shoreline similar to Karan and Kurayn Island.

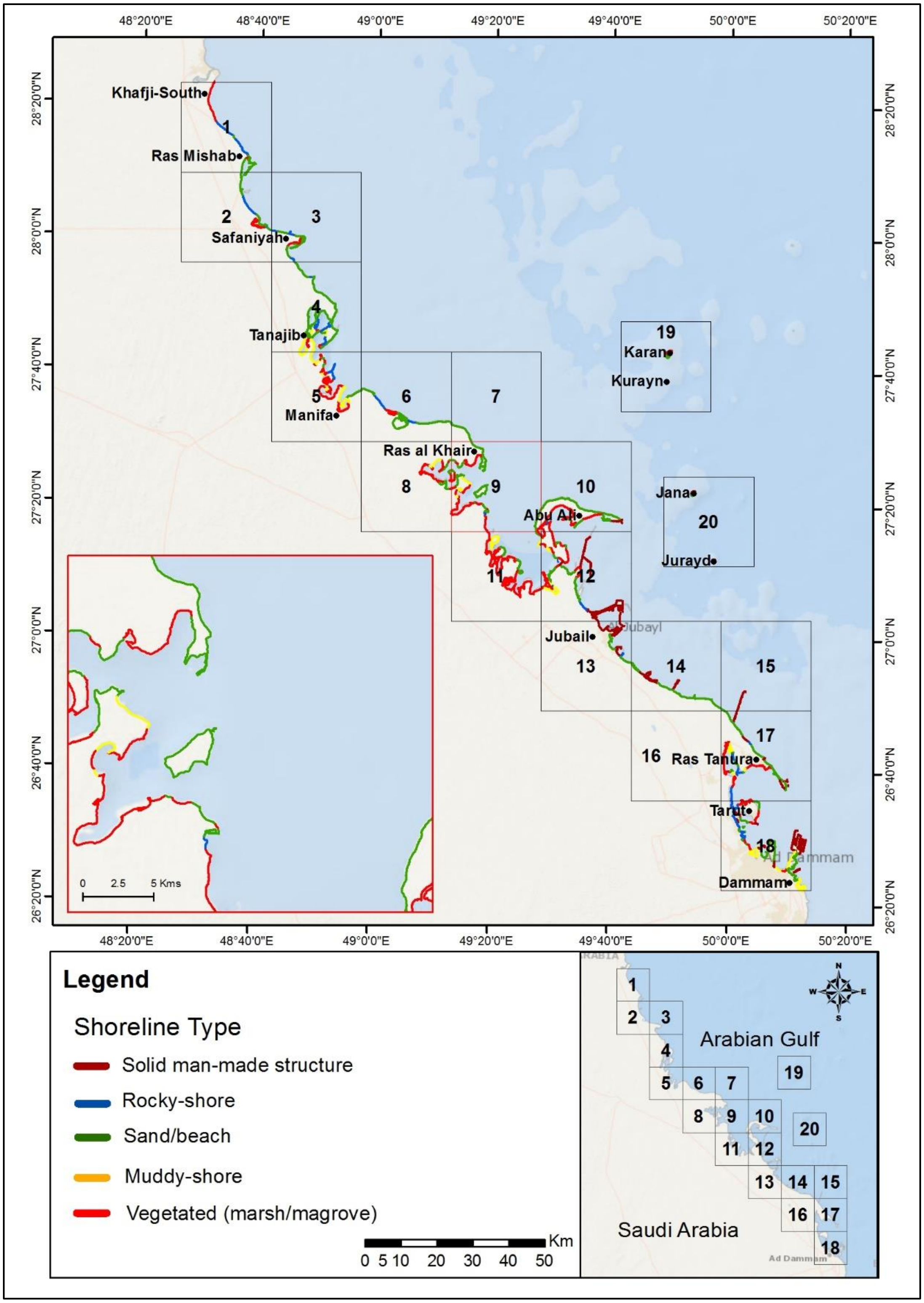



Figure 13. Shoreline type classification in the Western Arabian Gulf

Solid man-made structure

Rocky-shore

Vegetated (salt marshes) shoreline

Vegetated (mangrove) shoreline

Muddy-shore

Sandy-shore

Figure 14. Images of different shoreline type in the Gulf study area

The percentage of different shoreline types for the entire study area is shown in Figure 15. Within the study area sandy shoreline was dominant (around 49%), followed by muddy (23%), rocky (13%), solid man-made structures (8%), and the vegetated shoreline with salt-marshes (8%) and mangrove (4%).

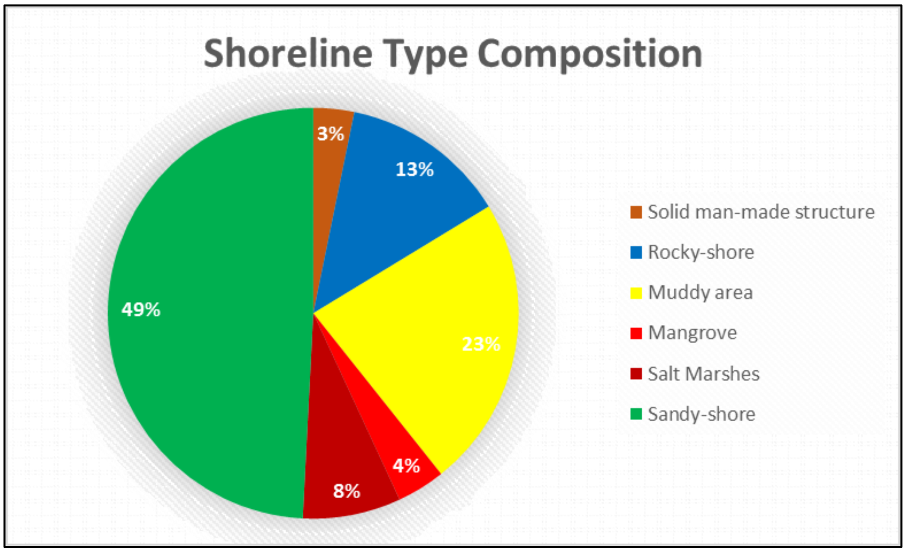



Figure 15. Shoreline type composition presented as percentage of the total length of the study area

### 4.1.2 Biological Resources

A biological resource classification is another important parameter of ESI maps. The ESI map for biological resources showed five sensitivity classes of marine habitat that could be impacted by oil spills. These types of biological resources consist of mangroves, salt marshes, seagrasses and corals. Coral types should be divided by two classes, coral heads and coral reef. Corals were given with red color, seagrasses with green, salt marshes with yellow and mangrove with purple color. These biological resources have been digitized and classified into polygonal areas in the ESI map (Figure 16).

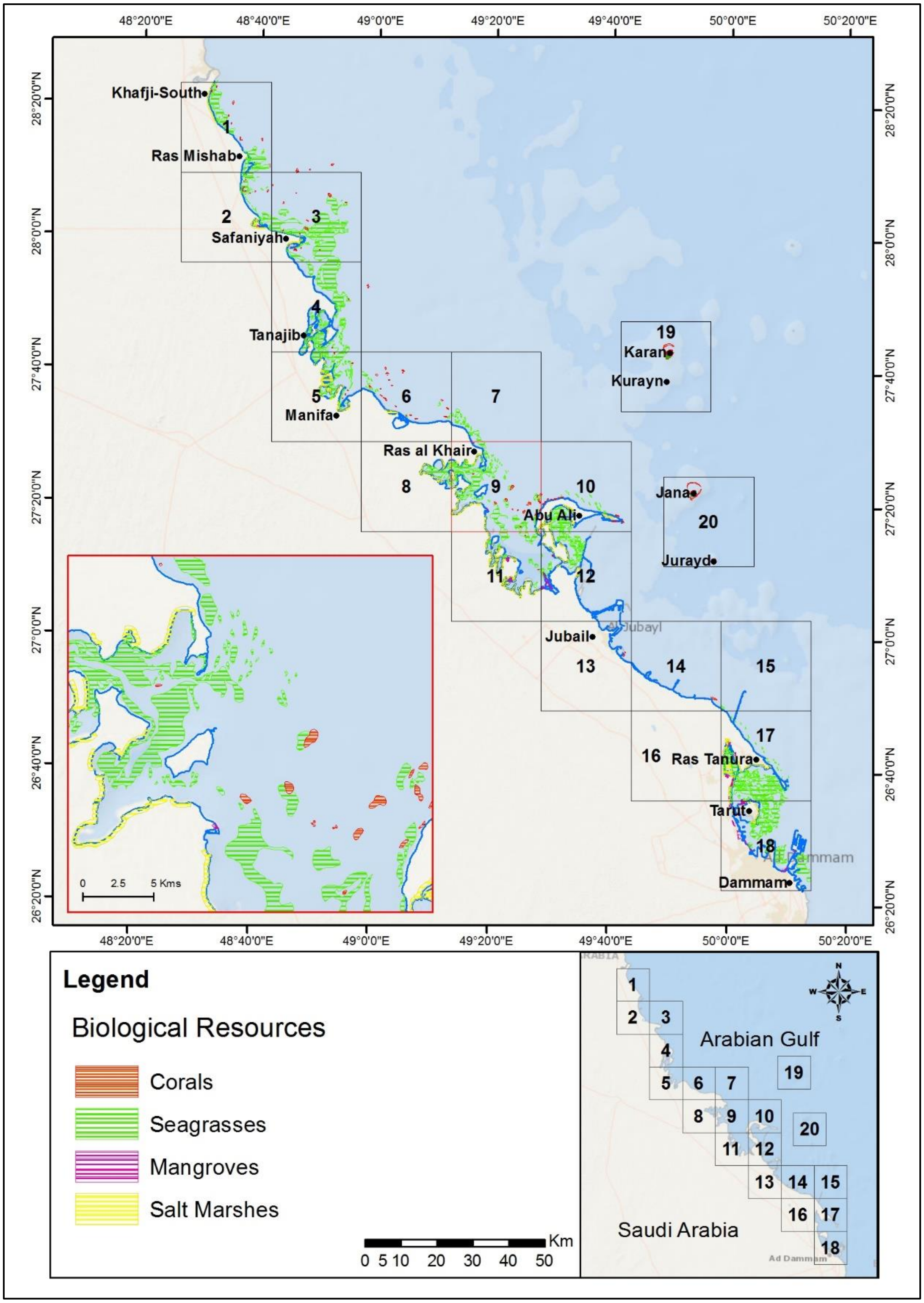



Figure 16. Biological resources classification in the Gulf study area

In Khafji and Ras Mishab area (Grids 1 and 2), several areas of seagrasses and scattered corals were located, and one area of salt marshes was shown in the shoreline. From Safaniyah to Tanajib (Grids 3 and 4), the seagrass area increased along with the Tanajib closed embayment. This area also had several areas of corals and salt marshes. Meanwhile, the seagrasses were reduced in Manifa embayment (Grid 5), but areas of salt-marshes increased as well as the number of corals locations.

In the northern-part of Ras al-Khair (Grid 6), very few of seagrass areas were mapped, but many corals were identified in this location. From Ras al-Khair closed embayment to Abu Ali Island (From grids 8 to 12), biological resources were very dense with seagrass, corals and salt-marshes noted. Salt-marshes were identified in Ras al-Khair tidal zone (Grid 11) and the southern-part of Abu Ali Island (Grids 10 and 12). Corals were identified in the northern-part of Abu Ali Island (Grid 9).

From Jubail to the northern-part of Ras Tanura (from grids 13 to 17), only a few sites of corals were identified and scattered seagrass occurred in Ras Tanura. While, in the southern-part of Ras Tanura (Grid 17), biological resources were identified as very dense and variable. Seagrasses occurred in the Tarut Bay, and salt marshes and mangrove growth was mapped in the Rahima and Safwa (Grid 17). Tarut Bay has been fully covered with seagrass and several mangrove sites occur in the northern-part and eastern-part of Tarut Island (Grid 18). There, the bay is now Dammam Seaport.

Most of the locations in this study possess biological resources. The denser and more variable biological resources occur from Safaniyah to Manifa, from Ras al-Khair to Abu Ali Island, and from Ras Tanura to Tarut Island. These areas have high sensitivity to impacts from potential oil spills.

### 4.1.3 Socio-economic Features

Socio-economic features in ESI map have been plotted and drawn with standard symbolization of icons and color code (Figure 17). The most sensitive locations were given with red color and features are shown with the color code based on the index already given. The brief information of socio-economic features and location attributes were attached in the appendix A.

From Safaniyah to Ras al-Khair (Grids 2 to 7), only a few of socio-economic features were identified. Most of the socio-economic features in these areas were classified as moderate sensitivity type, except Safaniyah GOSPs, and fish landing sites in Safaniyah and Manifa. While, from Ras al-Khair to Abu Ali Island, only fish landing sited were categorized as highly sensitive socio-economic features.

Jubail area (Grids 12, 13 and 14), includes various socio-economic features. Several high sensitivity features include oil and gas facilities such as Jubail Gas Plant, Jubail terminal and refinery, Jubail fish landing site, and desalination plants, i.e  Jubail plant and Saline Water Conversion Corporation plant. Other features varied from parks, municipalities sites, beaches, hospitals, educational sites, Jubail seaport, and industrial areas.

Ras Tanura to Dammam (Grids 16 to 18) includes various features, e.g. high sensitivity features such as the oil refinery in Ras Tanura and fish landing sites in Safwa, Dareen, Qateef and Sayhat. Other features are water discharges from agricultural activities and municipalities in Tarut Bay. Moreover, fish landing sites are also identified in the offshore islands i.e Karan, Kurayn, Jana and Jurayd Island (Grids 19 and 20).

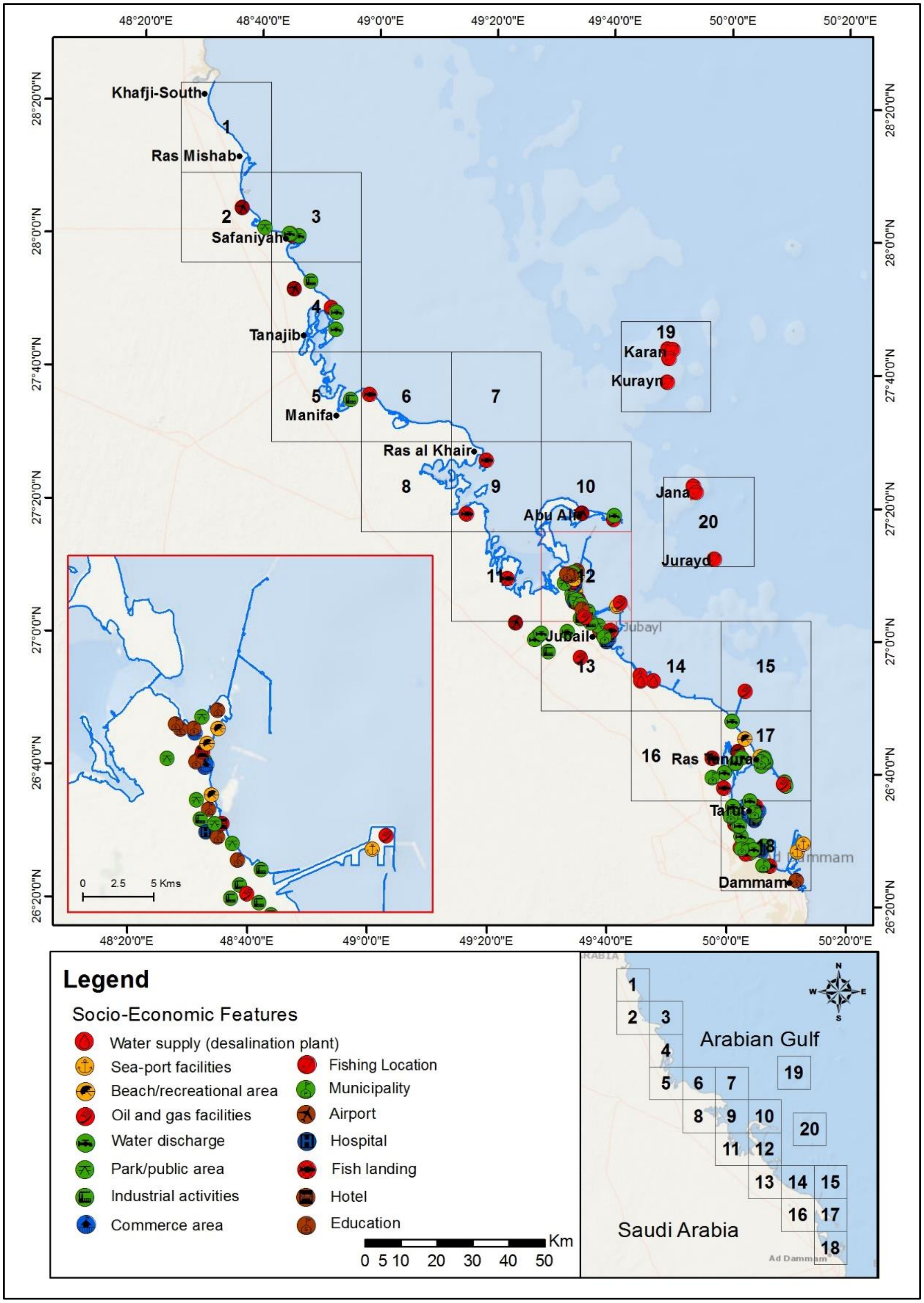



Figure 17. Socio-economic features in the Gulf Study area

### 4.1.4 Final Layout ESI Map

The final ESI map combined three parameters of ESI, i.e. shoreline-type classification, biological resources and socio-economic features. This map organization will aid the oil spill response policy makers and incident responders identify the several parameters in the field.

The map shown in Figure 18 is the final ESI map of the Gulf study area. The details of the map may not be clear, but that is due to the size of the layout. Typical ESI maps are normally produced in A3 or A1 size enabling the end-user to effectively use the maps. These also can be printed in every grid zones area (zoom-in) with acceptable scale (Figure 20). Table 4 shows the summary sensitivity result of ESI mapping in the Gulf study area.

Table 4. Summary Sensitivity Result of ESI Map

| Grid No. | Shoreline Type Classification | Biological Resources | Socio-economic Features | Sensitivity Remarks |
|---|---|---|---|---|
| 1 | Vegetated shoreline (saltmarshes), rocky-shore, sandy-shore | Salt marshes, dense seagrasses and scattered corals | No features | Moderate |
| 2 | Sandy-shore, less rocky-shore and few vegetated shoreline (salt-marshes) | Sparse seagrass and scattered corals | Airport and park | Moderate |
| 3 | Sandy-shore, less rocky-shore and few vegetated shoreline (salt-marshes) | Highly dense seagrasses and scattered corals | Water discharge and fish landing and GOSP Safaniyah | High |

| Grid No. | Shoreline Type Classification | Biological Resources | Socio-economic Features | Sensitivity Remarks |
|---|---|---|---|---|
| 4 | Mostly sandy-shore, and few muddy-shore and vegetated shoreline (salt-marshes) | Dense seagrasses and scattered corals | Airport, industrial area, water discharge and Tanajib terminal facilities | Moderate |
| 5 | Highly vegetated shoreline (salt-marshes) and muddy-shore | Salt marshes, dense seagrasses and scattered corals | Saudi Aramco - Manifa Camp | High |
| 6 | Sandy-shore, rocky-shore and few vegetated shoreline (salt-marshes) | Few seagrass and scattered corals | Manifa fish landing | Moderate |
| 7 | Sandy-shore | Seagrass | No features | Low |
| 8 | Highly vegetated shoreline (salt-marshes) and muddy-shore | Seagrass and salt marshes | No features | Moderate |
| 9 | Highly vegetated shoreline (salt-marshes) and muddy-shore with sandy-shore in the island | Salt marshes, highly dense seagrasses and scattered corals | Fish landing | High |
| 10 | Sandy-shore and vegetated shoreline (salt-marshes) | Sparse seagrasses and scattered corals | Airport, Berri GOSP and water discharge | High |
| 11 | Highly vegetated shoreline (salt- | Salt-marshes, seagrasses and | Fish landing | High |

| Grid No. | Shoreline Type Classification | Biological Resources | Socio-economic Features | Sensitivity Remarks |
|---|---|---|---|---|
| | marshes) and muddy-shore | corals | | |
| 12 | Sandy-shore and few of rocky-shore | Salt-marshes, seagrasses and corals | Industrial areas, seaport facilities, beaches, parks, commerce areas, educational sites, hospital, Jubail terminal and refinery | High |
| 13 | Sandy-shore and few of rocky-shore | Few corals | Industrial areas, seaport facilities, airport, water discharge, Berri Gas plant, Jubail refinery, fish landing and municipality | Moderate |
| 14 | Sandy-shore and few of rocky-shore | Few corals | Jubail desalination plant, Saline water conversion plant | High |
| 15 | Sandy-shore | Few seagrass | NGL Loading facilities | Moderate |
| 16 | No shoreline | No biological resources | Fish landing and municipality | Low |
| 17 | Sandy-shore, highly vegetated shoreline | Dominated salt-marshes, | Airport, beaches, water discharges, | High |

| Grid No. | Shoreline Type Classification | Biological Resources | Socio-economic Features | Sensitivity Remarks |
|---|---|---|---|---|
| | (salt-marshes and mangrove) and few muddy-shore | mangrove, and highly dense seagrasses | fish landing, municipality, and Ras Tanura oil refinery | |
| 18 | Highly vegetated shoreline (salt-marshes and mangrove), rocky-shore, muddy-shore and solid man-made structure | Dense seagrasses, salt-marshes and mangroves | Seaport facilities, parks, hospital, commerce areas, Saihat water conversion plant, fish landings, water discharges, educational sites and municipality | High |
| 19 | Vegetated shoreline (salt-marshes) and sandy-shore | Surrounded by corals reef | Fishing location | High |
| 20 | Vegetated shoreline (salt-marshes) | Surrounded by corals reef | Fishing location | High |

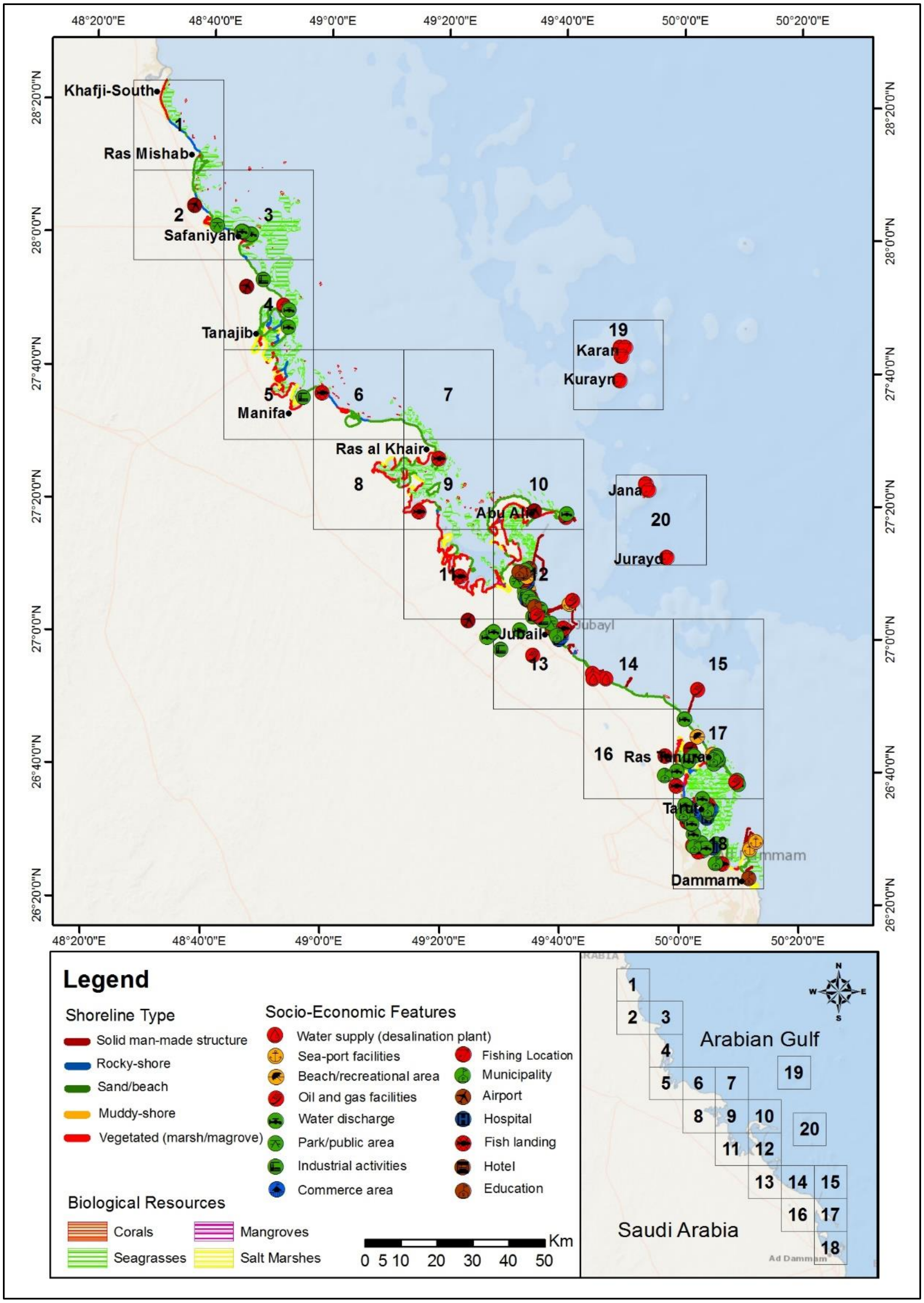



Figure 18. Complete ESI map layout with three component parameters

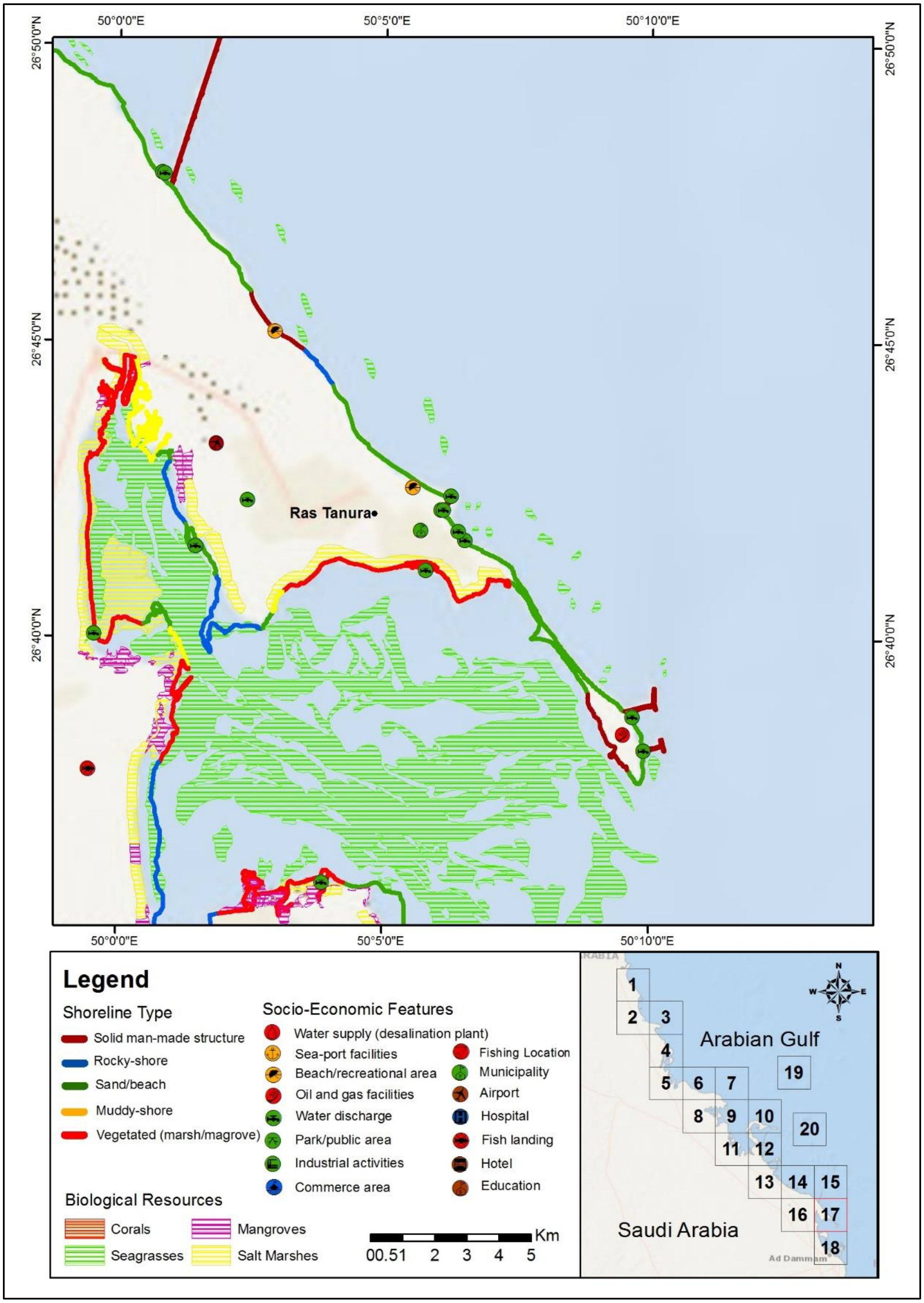



Figure 19. Detail ESI map in grid zone (17) in the Gulf study area

## 4.2 ESI Ranking of Environmental Sensitivity

ESI ranking incorporated shoreline type, biological resources and socio-economic features in the Gulf study area. Spatial distribution analysis was processed using Kernel spatial density analysis to obtain the grading of environmental sensitivity for each parameter in the study area. It was classified into five levels, i.e., extreme sensitivity, high sensitivity, moderate sensitivity, low sensitivity and non-sensitivity, based on relevant data and ESI index standard that simplified before (Figure 20).Due to the different data sources of the indicators, the values of the indicators for each analysis were obtained through buffer and rasterizing (changing from vector to raster data).

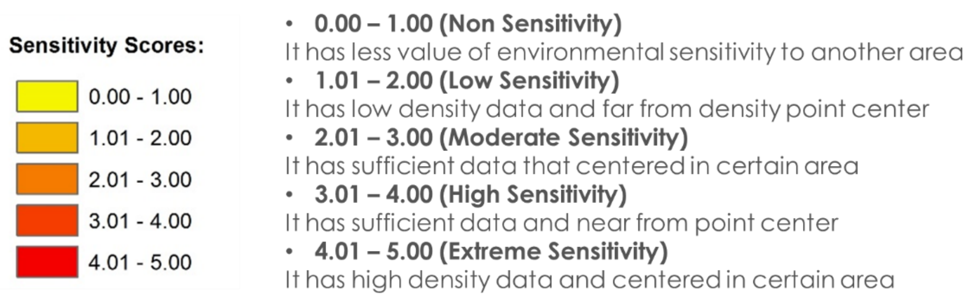



Figure 20. Sensitivity score criteria derived from spatial analysis in ArcGIS

### 4.2.1 Shoreline type sensitivity area

Shoreline type sensitivity areas were distributed in several areas. These include Tanajib to Manifa, from Ras al-Khair to Abu Ali, and from Ras Tanura to Tarut Island. While, less sensitivity was noted in Dammam area and Jubail (Figure 21). Khafji area is a non-sensitive area for shoreline sensitivity as well as several areas in grid 14. The offshore islands have shoreline type sensitivity with salt-marshes in terrestrial and surrounded by corals.

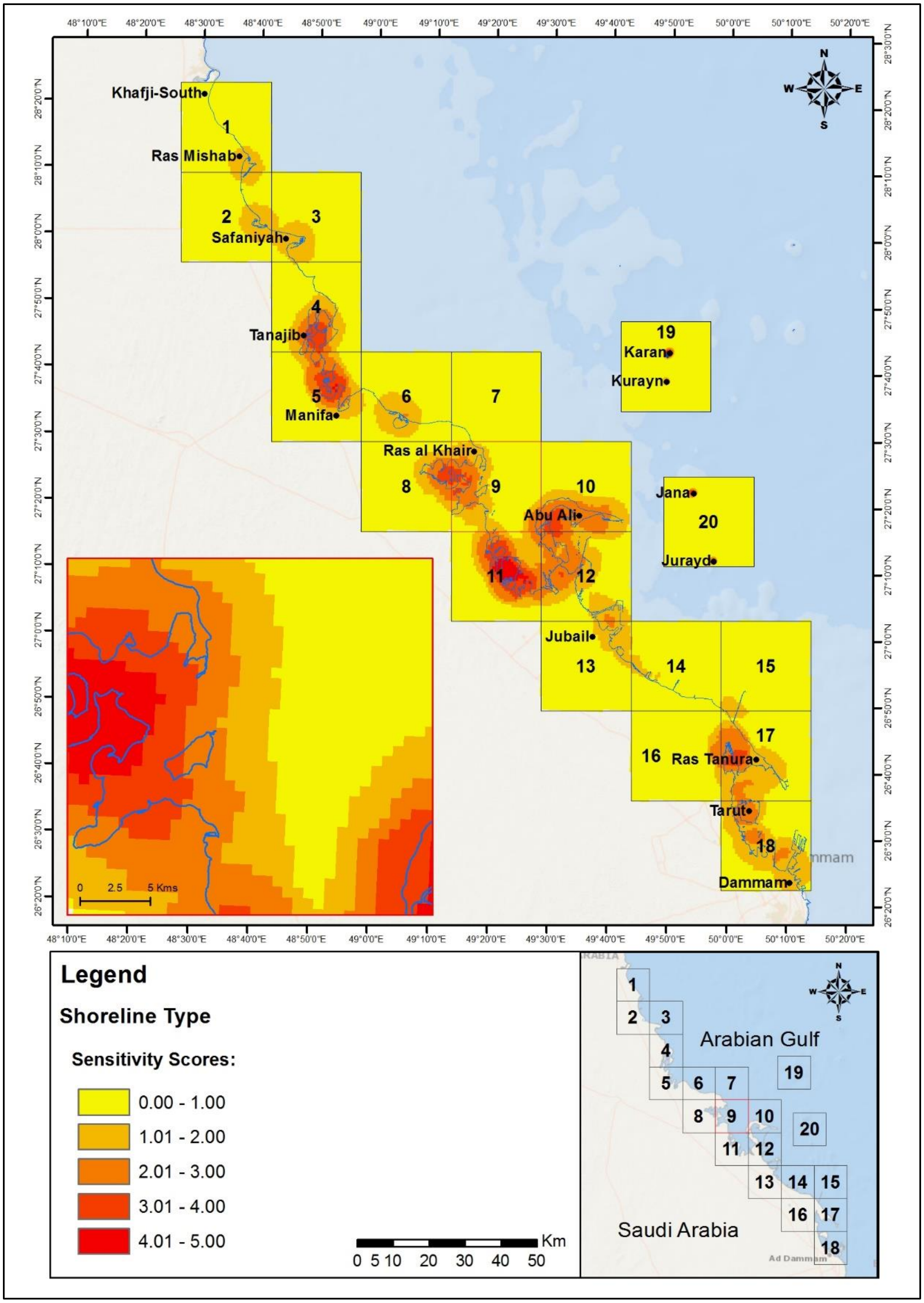



Figure 21. Shoreline type after spatial analysis with different sensitivity score

### 4.2.2 Biological Resources

Biological resources sensitivity areas were mostly available in the study area. These include Ras Mishab to Safaniyah, from Tanajib to Manifa, from Ras al-Khair to Abu Ali, and from Ras Tanura to Tarut Island (Figure 22).

From Ras Mishab to Manifa, biological resources were mostly dominated by seagrass and several corals. This condition is the same as from Tanajib to Manifa, where biological resources were dominated by seagrass and several corals. The condition has a few differences in composition of biological resources from Ras Al-Khair to Abu Ali Island that were more dominated by coral rather than seagrass, and where several intertidal areas including a lot of salt-marshes occurred. From Ras Tanura to Tarut Island, biological resources were mostly dominated by seagrass, salt-marshes and several mangrove areas.

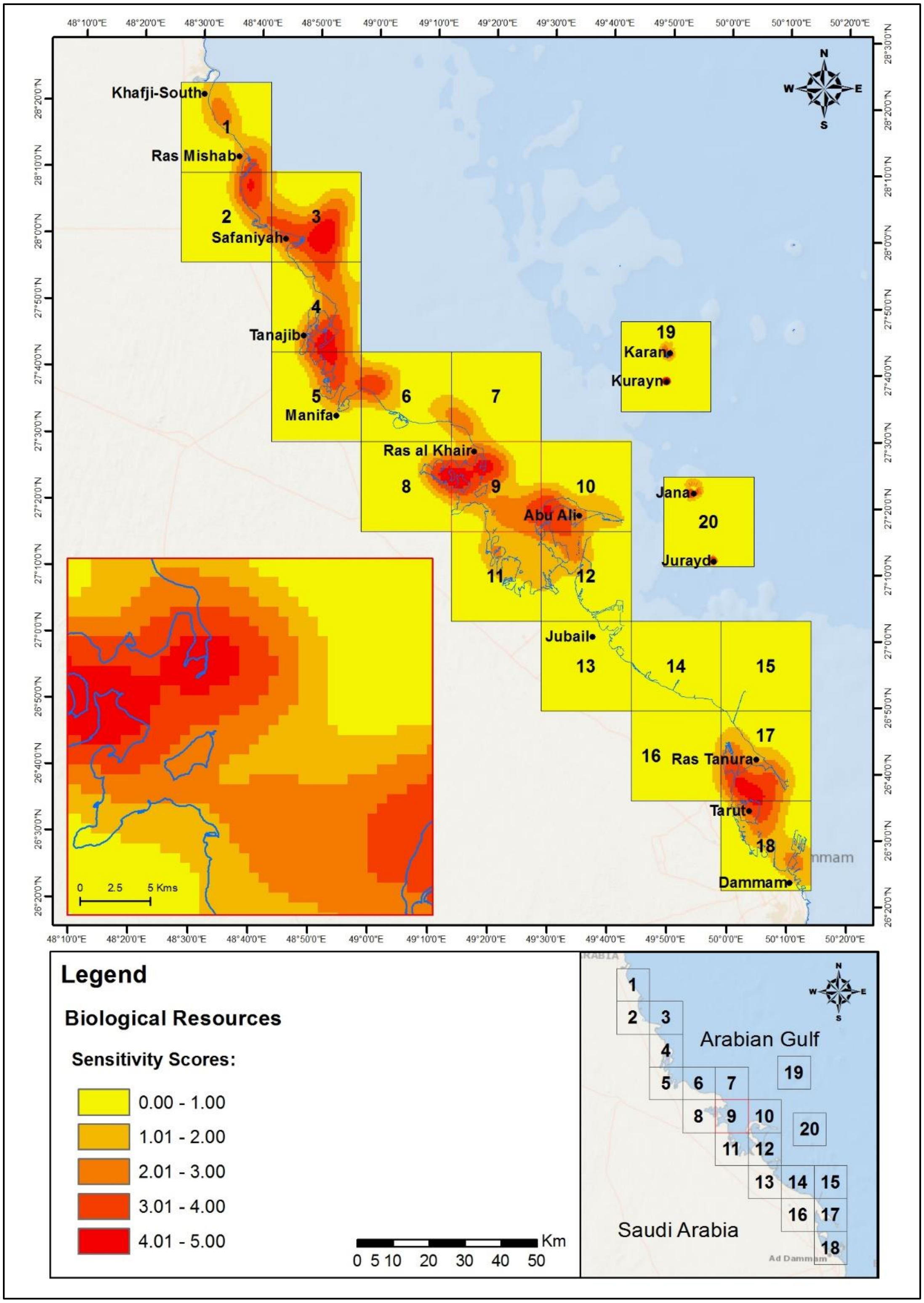



Figure 22. Biological resources after spatial analysis with different sensitivity score

### 4.2.3 Socio-economic Features

Socio-economic features sensitivity areas were mostly located in two areas: Jubail, and from Tarut Island to Dammam, with less sensitivity found in Ras Tanura (Figure 23). These conditions refer to many activities that could be affected by oil spills. Jubail has an industrial area that may have more density in terms of area of sensitivity. Dammam area is a populated area that could find many activities related to spills occurring.

Jubail area has desalination plant that serves as an important water supply in the local and regional area. This type of socio-economic feature is most important and has enormous impact since it takes water from the sea as the source of desalinated water for both municipal and industrial supplies. Besides that, the power plant also has high sensitivity to oil spills since this socio-economic feature uses sea water in its cooling tower.

In the Dammam area, the municipality is the dominant socio-economic feature including the facilities surrounding it, such as market areas, the sea port and oil and gas facilities in Ras Tanura. In this area, public areas such as parks, beaches, and several schools and universities are found.

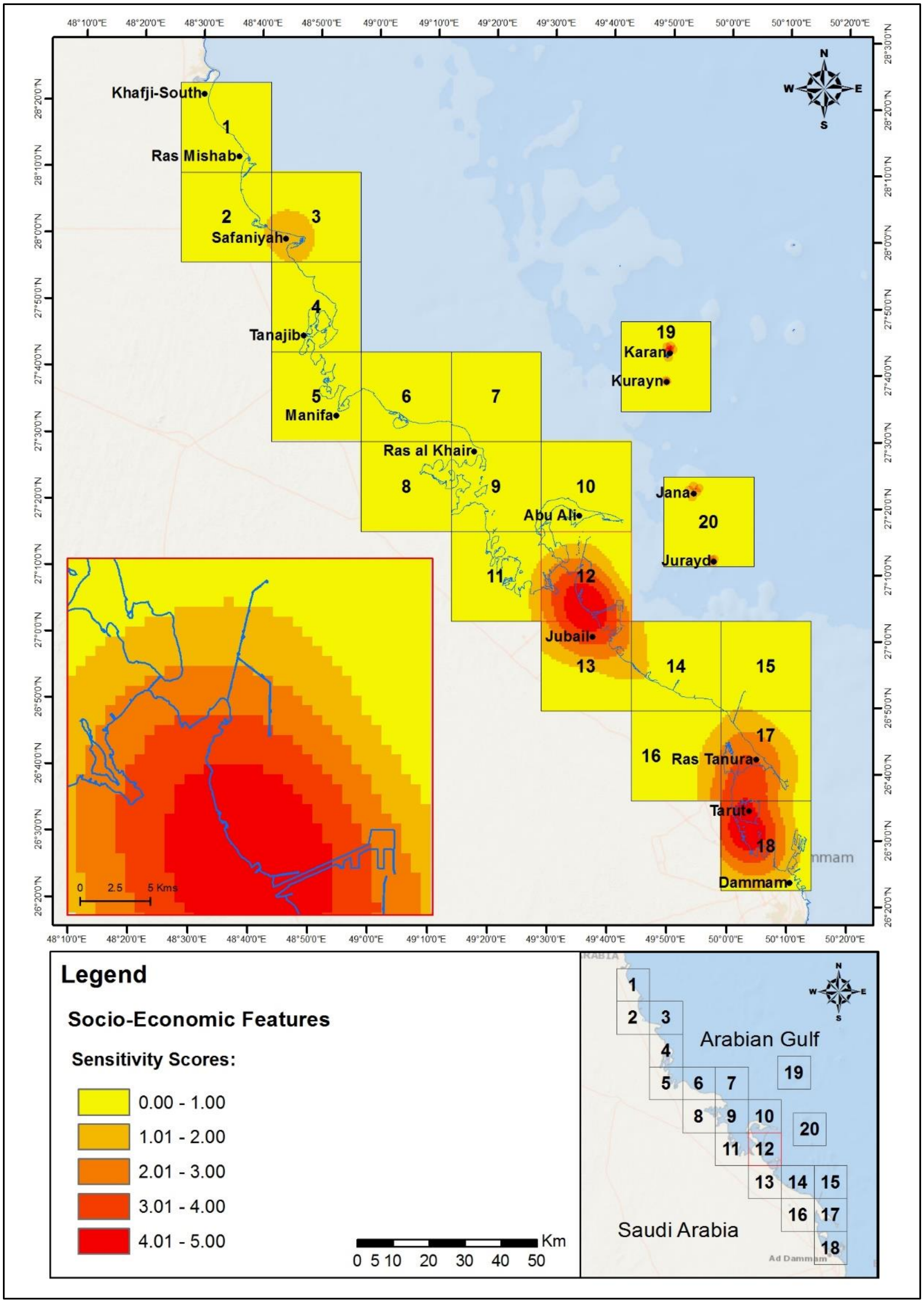



Figure 23. Socio-economic features after spatial analysis with different sensitivity score

### 4.2.4 ESI Map Priority for Oil Spill Response

ESI parameters have been classified into different sensitivity rankings. The ranking sensitivity shows three locations of first priority for oil spill responses. The locations for the first priority were Safaniyah area, Abu Ali-Jubail area, Ras Tanura, Tarut Island and Dammam, and offshore islands area, i.e. Karan, Kurayn, Jana and Jurayd Islands (Figure 24). These first priority locations satisfied with three different ESI parameters on sensitivity. These were classified with sensitive shoreline type, biological resources and socio-economic features in surrounding area.

The second priority oil spill responses were located in Ras Mishab, Tanajib, Manifa, Ras al-Khair, Abu Ali and Jubail area. Four locations (Ras Mishab, Tanajib, Manifa, Ras al-Khair, and Abu Ali) had sensitive shoreline type, biological resources, but lack of socio-economic features. While, Jubail area had sensitive shoreline type and socio-economic features, but lack of biological resources. The third priority oil spill responses were located nearby the second priority areas. This means that, these locations only had one sensitivity parameter in surrounding areas.

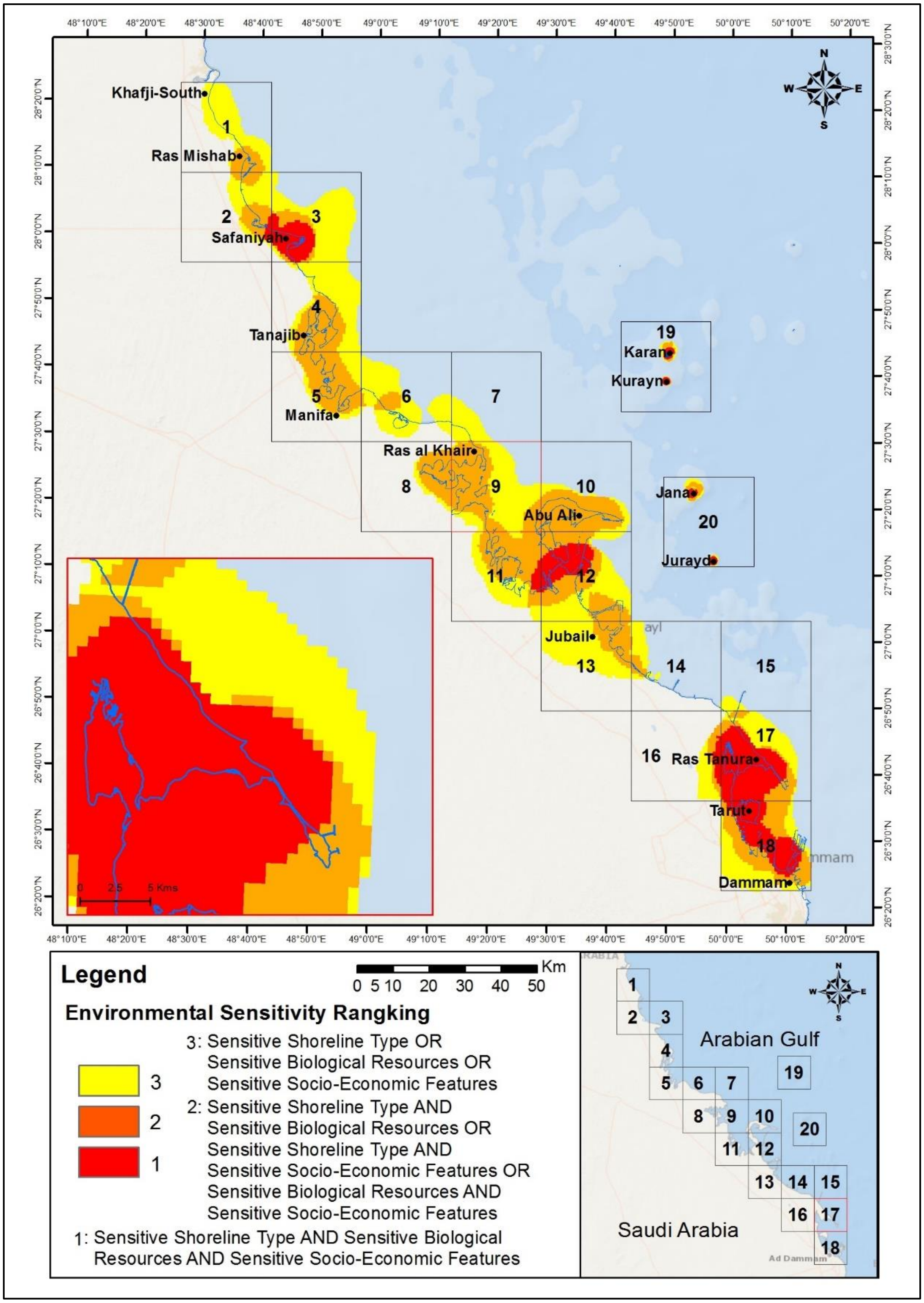



Figure 24. Overlaying sensitivity area with priority ranking of oil spill response

# CHAPTER 5

# DISCUSSIONS

## 5.1 The proposed ESI Map for Oil Spill Response

Oil spill response is a complex and challenging cross-disciplinary planning area. In the operational decision-making process, spill response combines a wide range of issues and activities under emergency response conditions. These include: the nature of the material spilled, which undergoes changes in physical and chemical properties (weathering) over time, local environmental conditions, sensitivity of impacted natural resources, and selection and effectiveness of response/clean-up technologies (Fingas, 2012). The ESI map prepared in this study can help the oil spill responder to know which area needs to be protected firstly after using oil spill modeling, where the oil will impact directly.

The assessment of environmental sensitivity may provide important information that supports oil spill response planning. The information is color coded as per the grade of sensitivity of each parameter. These parameters include shoreline-type classification, biological resources, and socio-economic features that have implication for oil spill response, most affected during the clean-up process, and features that may help during the clean-up process.

### 5.1.1 Shoreline Type

Shoreline-type classification gives the status of shoreline sensitivity for selecting a better clean-up process. In coastal environments, the vegetated shoreline type have a high likelihood of being directly oiled when the oil spill impacts the shoreline directly (NOAA, 2002). Vegetated shoreline type is the highest sensitivity because of the difficulties of the clean-up process, especially mangrove areas where complex ecosystem life occurs, and where habitat is very important for other organisms (Beisl, et al., 2003). The oil fate and effects have been recognized as shore-type dependent, and most of the clean-up methods are specific with shoreline type (Hayes and Michel, 1997; Gundlach and Hayes, 1978). In this study, Manifa, Khursaniyah and Tarut Bay were the most sensitive areas for shoreline type, followed by Safaniyah, Tanajib, Ras al-Khair, and Abu Ali. These areas were mostly vegetated with salt-marshes in several places, and mangroves in Khursaniyah and Tarut Bay coastal areas. Low sensitivity shoreline type areas were located in Jubail, Ras Tanura and Dammam, because these areas show mostly solid man-made structures for seaport or recreational areas.

Shoreline types were mapped with different colors to indicate their sensitivity to oil spills. On ESI maps, warm colors like orange and red are used to indicate the shorelines that are most sensitive to oil; these include tidal flats and swamps (NOAA, 2002). Cool colors, like blue and purple denote the least sensitive shorelines, such as rocky headlands and sand and gravel beaches, as observed in Ras Mishab, Ras al-Khair and Abu Ali (northern-part). Shades of green denote shorelines of moderate sensitivity (NOAA, 2002) and brown color or dark color for man-made structure (ESRI, 2010) as observed in Jubail and Ras Tanura in this study.

The dominant shoreline type identified within the study area was sandy-shore. Generally, the Gulf shoreline is moderate sensitivity for shoreline type and it is easy to access the shoreline in case of oil spill. While most of the land-use developments extend to the shoreline, such as the Jubail as industrial area,Tarut Island and the Dammam municipal area development.

### 5.1.2 Biological Resources

Biological resources provide essential information for environmental sensitivity mapping. The mapping provides the different categories of the marine habitats that will be affected by oil spills. Mangrove is the most impacted habitat if the oil spill reaches the shoreline (NOAA, 2002) along with salt-marshes. Habitat or biological resources also mapped in this study include seagrasses and corals. Seagrass has low sensitivity because it becomes less impacted or not directly impacted. Seagrasses occupy the sub-tidal areas and may not have much impact from oil spill, if the oil remains predominantly in the water surface.

In this study, importance was given to biological resources of the intertidal and subtidal habitats. However, the ESI maps sometimes present the biota occurring in the study area. Generally, the biota are not ranked in terms of sensitivity and it is not even incorporated in the sensitivity ranking (Carmona, et al, 2006 and Wieczorek, et al., 2007). The reason behind this is the seasonal characteristics of these resources. The approach that is always used in ESI mapping is to map the biological resources; those that are sensitive to oil are mapped separately and then included with appropriate symbolization on the ESI map. Hence, this information could also be taken into account by the responder in the case of a real spill event (Krupp and Abdulaziz, 2008). Another reason is the biota such as birds may have short-term damage from oil spills since they are mobile or migratory in nature (Evans, et al, 1993). Even nesting areas should be mapped in ESI mapping for oil spill preparedness and responses. Offshore islands within the study area are known for bird and turtle nesting, for example (Saudi Aramco, 2014).

### 5.1.3 Socio-economic Features

The most important and sensitive socio-economic features within the study area are the desalination plants. There are several desalination plants in the study area and these features categorized as being of the highest sensitivity with the red color code together with fish landing areas, and oil and gas facilities. Desalination plants use the seawater as their raw water and oil spills adversely affect the seawater quality and hence the operation of the facilities. Therefore, water-intake facilities for desalination plants require protection from oil spills. ESI map studies conducted for the Amazon Coast, Brazil (Souza, et al. 2004); São Paulo State coastline, Brazil (Carmona, et al, 2006); Cardoso Island State Park, Brazil (Wieczorek, et al., 2007) did not consider the desalination plant as sensitive facilites. However, as per the NOAA guidelines, desalination plants have to be categorized as a water supply source and given the highest priority while making ESI maps (NOAA, 2002).

## 5.2 Zoning Prevention for Environmental Sensitivity Area

The idea behind displaying sensitivity ranking by using the accumulation of sensitivity parameters with different color coding (heat-map) is to make possible the brief view of areas vulnerable to oil spills, and thereby facilitate preparedness and response (Zirpolo, 2014). Better understanding requires the situational perspective with regard to different parameters. In this study, the environmental sensitivity was mapped with different density of the sensitivity, in order to make the oil spill responder know the sensitivity areas along the Gulf coast and for the policy decision maker to be able to determine the general response strategy at national or regional levels (IPICEA, 2012).

Sensitivity ranking can be incorporated with the ESI base map, to know the condition in the sensitive area in order to make specific response strategy (Figure 25). The red area (first priority) has three sensitivity parameters, such as vegetated shoreline type, dense biological resources, such as seagrass, salt-marshes and mangrove, as well as the socio-economic features (oil and gas facilities, discharge locations and recreational areas).

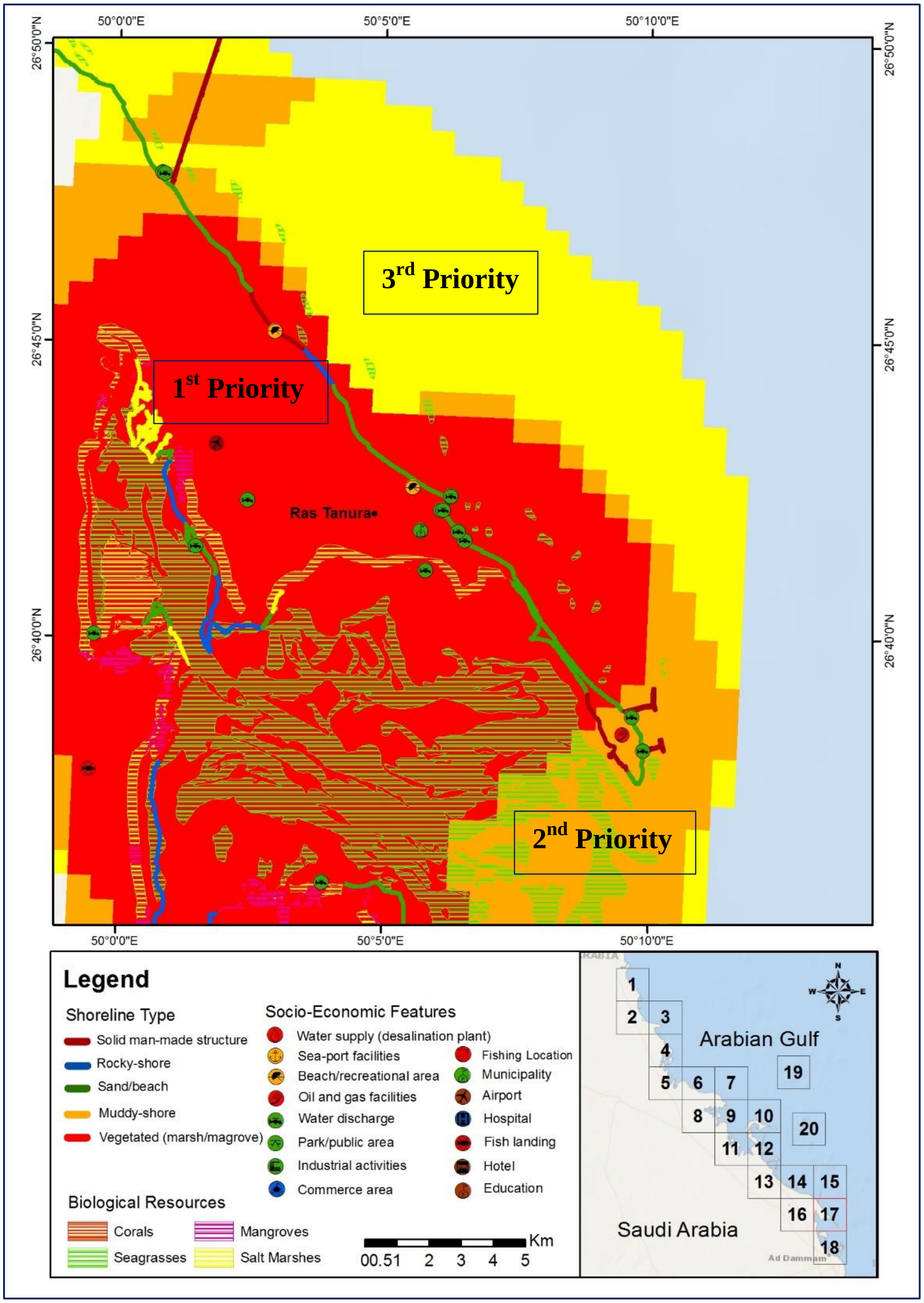



Figure 25. Zoning Sensitivity Area for Protection from Oil Spill

# CHAPTER 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

The Environmental Sensitivity Index (ESI) map produced by this study could be part of the oil response plan in the Gulf study area. The map gives the oil spill responders a summary of the coastal environments including shoreline type, biological resources and socio-economic features with the applicable sensitivity scoring. Shoreline types give the information for oil spill clean-up processes, particularly if the oil spill has been directly in contact with the shoreline. Biological resources show the habitat location and area that could be impacted by an oil spill. Socio-economic features lead the oil spill responder to the location that should receive priority protection.

The following shoreline sensitivity areas were identified:

- From Ras Al-Khair to Abu Ali Island with dense vegetated shoreline (salt-marshes),
- From Ras Tanura to Tarut Island with dense vegetated shoreline (salt-marshes and mangroves), and
- Tarut Bay area with mangroves and salt marshes along the shoreline.

The following biological resources sensitivity areas were identified:

- From Ras Mishab to Manifa coast that having dense seagrass and scattered corals,
- From Ras al-Khair to Abu Ali Island and, Tarut Bay coast that having dense seagrasses and mangroves, and
- Offshore islands that are surrounded by rich coral communities.

Finally, the socio-economic features sensitivity areas were mostly located in Jubail area that has industrial area, oil and gas facilities and desalination plants and from Ras Tanura to Dammam that has many recreational areas, oil and gas facilities and seaports.

Spatial analysis has been conducted in GIS format to analyze the sensitivity area of parameter sensitivity score and achieve the cumulative sensitivity area condition in order to get the sensitivity ranking. Based on those results, the first priority areas that have to be protected are: Safaniyah, Khursaniyah-Jubail, Tarut Bay and Offshore Islands in case of oil spills that may reach those locations. These identified sensitivity areas reflect the sensitivity characteristics to oil spills and need further analysis when it comes to small or specific areas.

The developed ESI map for the study area is a thematic map of three main parameters that could be sensitive to oil spill with different sensitivity rankings. This map assumes that the real event of an oil spill is already underway, and that oil reached the shoreline. This type of map will give direction to the oil-spill responder and make protection the priority of biological resources and socio-economic features after making oil spill tracking available with an oil spill modeling study. This map also gives the information required for the shoreline clean-up procedure in case of an oil spill. For the application, it has to be incorporated with oil spill tracking system or modeling as the base-map for oil spill response in a decision support system (DSS).

## 6.2 Recommendations

This study has covered a large area--from Khafji to Dammam--and gives the brief information about sensitivity areas for oil spill response in the Gulf study area. The general topic needs more study in specific areas (sensitive areas in this study) for more detailed information, and to consider new socio-economic changes. The developed ESI map in this study is not a risk assessment analysis for oil spill response, a full risk assessment would need more study with different methods to achieve a suitable result with this information provided in the present study.

Some limitations have been encountered in this study and additional necessary works need to be done in the future. Therefore, a few things are recommended for additional study; these are mentioned below:

- More detailed information on sensitive areas that are presented in this study, such as Safaniyah, Khursaniyah-Jubail, Tarut Bay and offshore islands.
- Better analysis of remote sensing data with other technical methods such as band ratio with water correction for better understanding the biological resources below the water.
- Developing oil-spill response applications that can incorporate the ESI map with oil spill modeling to achieve practical simulation or application in the field in case of oil spill.

- Assessing the effect or damage of oil spill to biological resources, such as mangrove, salt-marshes, coral reef and seagrasses with ecological modeling for better sensitivity index analysis.
- Several study topics about environmental sensitivity for other environmental issues, such as high temperature water pollution, industrial or energy development, and climate change effects on biological resources and sea level rise that may change the shoreline.

# References


Abdel-Kader, A. F., Nasr, S. M., El-Gamily, H. I., & El-Raey, M. (1998). Environmental sensitivity analysis of potential oil spill for Ras-Mohammed coastal zone, Egypt. Journal of coastal research, 502-510.

Al-Saad, H. T., & Salman, N. A. (2012). Status of Oil Pollution in the Arabian Gulf and Shatt Al-Arab Estuary: A Review. In Coastal Environments: Focus on Asian Regions (pp. 36-46). Springer Netherlands.

Basson, P. W. B., Hardy, J. E., & Price, J. T. (1977). Biotopes of the Western Arabian Gulf marine life and environments of Saudi Arabia (No. 574.52636 B5).

Beisl, C. H., Miranda, F. P., Pedroso, E. C., & Landau, L. (2003). Generation of oil sensitivity index information in western Amazonia, Brazil, using dual season SAR image mosaics of the global rain forest mapping project. Simpósio Brasileiro de Sensoriamento Remoto, 11, 823-830.

Bell, J., & Lovelock, C. E. (2013). Insuring mangrove forests for their role in mitigating coastal erosion and storm-surge: an australian case study. Wetlands, 33(2), 279-289.

Canters, F. (2004). Geographical Information Systems, course notes. Department of Geography, Vrije Universiteit Brussel (VUB), Belgium

Carmona, S. L., Gherardi, D. F. M., & Tessler, M. G. (2006). Environment sensitivity mapping and vulnerability modeling for oil spill response along the São Paulo State coastline. Journal of Coastal Research, 1455-1458.

Castanedo, S., Juanes, J. A., Medina, R., Puente, A., Fernandez, F., Olabarrieta, M., & Pombo, C. (2009). Oil spill vulnerability assessment integrating physical, biological and socio-economical aspects: Application to the Cantabrian coast (Bay of Biscay, Spain). Journal of environmental management, 91(1), 149-159.

Clayton, J.R., Jame R. Payne, John S. Faelow. (2000). Oil Spill Mechanism of Action and Laboratory Test. Florida: C.K. Smoley.

de Castro, A. F., Grigio, A. M., Souto, M. V. S., Amaro, V. E., & Vital, H. (2006). Modeling and Development of a Geographic Database: Application to the elaboration of oil-spill environmental sensitivity maps in coastal areas of the Rio Grande do Norte State. Journal of Coastal Research, 1436-1440.

El-Raey, M., Abdel-Kader, A. F., Nasr, S. M., & El-Gamily, H. I. (1996). Remote sensing and GIS for an oil spill contingency plan, Ras-Mohammed, Egypt. International journal of remote sensing, 17(11), 2013-2026.

Evans, M. I., Symens, P., & Pilcher, C. W. T. (1993). Short-term damage to coastal bird populations in Saudi Arabia and Kuwait following the 1991 Gulf War marine pollution. Marine Pollution Bulletin, 27, 157-161.

Fingas, M. (2012). The basics of oil spill cleanup. CRC Press.

Furlan, A., Bonotto, D. M., & Gumiere, S. J. (2011). Development of environmental and natural vulnerability maps for Brazilian coastal at São Sebastião in São Paulo State. Environmental Earth Sciences, 64(3), 659-669.

Garza-Gil, M. D., Prada-Blanco, A., & Vázquez-Rodríguez, M. X. (2006). Estimating the short-term economic damages from the Prestige oil spill in the Galician fisheries and tourism. Ecological Economics, 58(4), 842-849.

Gundlach, E. R., & Hayes, M. O. (1978). Vulnerability of coastal environments to oil spill impacts. Marine technology society Journal, 12(4), 18-27.

Guzman, H.M., Jackson, J.B.C., Weil, E. (1991). Ecological consequences of a major oil spill on Panamanian subtidal reef corals. Coral Reefs, Vol. 10: 1–12

Guzman, H.M. and Holst, I. (1993). Effects of chronic oil sediments pollution on the reproduction of Caribbean reef coral – Siderastrea sidera. Marine Pollution Bulletin, Vol. 26: 276–282

International Petroleum Industry Environmental Conservation Association (IPIECA), International Maritime Organization (IMO) 2012. Sensitivity Mapping for Oil Spill Response.

The International Tanker Owners Pollution Federation (ITOPF). (1991). Response to Marine Oil Spill. London: Witheby Co., Ltd.

Jensen, J. R., Ramsey III, E. W., Holmes, J. M., Michel, J. E., Savitsky, B., & Davis, B. A. (1990). Environmental sensitivity index (ESI) mapping for oil spills using remote sensing and geographic information system technology. International Journal of Geographical Information System, 4(2), 181-201.

Jensen, J. R., Halls, J. N., & Michel, J. (1998). A systems approach to Environmental Sensitivity Index (ESI) mapping for oil spill contingency planning and response. Photogrammetric Engineering and Remote Sensing, 64, 1003-1014.

Jensen, J. R., Narumalani, S., Weatherbee, O., Murday, M., Sexton, W. J., & Green, C. J. (2008). Coastal environmental sensitivity mapping for oil spills in the United Arab Emirates using remote sensing and GIS technology. Geocarto International, 8(2), 5-13.

Krupp and Abdulaziz, 2008. Impact of oil pollution and increased sea surface temperatures on marine ecosystems and biota in the Gulf, from Barth, H. J., Krupp, F., Böer, B., & Al Abdessalaam, T. Z. (Eds.). Protecting the Gulf's Marine Ecosystems from Pollution. Basel: Birkhauser.

Koenig, C. C., Coleman, F. C., Eklund, A. M., Schull, J., & Ueland, J. (2007). Mangroves as essential nursery habitat for goliath grouper (*Epinephelus itajara*). Bulletin of Marine Science, 80(3), 567-585.

Saudi Aramco. 2014. Marine Atlas of Western Arabian Gulf.

Mendelssohn, I. A., Andersen, G. L., Baltz, D. M., Caffey, R. H., Carman, K. R., Fleeger, J. W., & Rozas, L. P. (2012). Oil impacts on coastal wetlands: implications for the Mississippi River Delta ecosystem after the Deepwater Horizon oil spill. BioScience, 62(6), 562-574.

Morales-Caselles, C., Kalman, J., Riba, I., & DelValls, T. A. (2007). Comparing sediment quality in Spanish littoral areas affected by acute (Prestige, 2002) and chronic (Bay of Algeciras) oil spills. Environmental Pollution, 146(1), 233-240.

Nxumalo, G.M., Lee, J.T. Ross, S.G, and ERM Ltd. (2013). Marine and Coastal Sensitivity Mapping for Oil Spill Preparedness and Response. Society of Petroleum Engineers. SPE European HSE Conference and Exhibition 16–1 8 April 2013, London, UK.

NOAA (National Oceanography and Atmospheric Administration). 2002. Environmental Sensitivity Index Guidelines, Version 3.0. NOAA Technical Memorandum NOS OR&R 11, Hazardous Materials Response Division, Office of Response and Restoration, NOAA Ocean Service.

Nouri, J., Fatemi, M. R., Danekar, A., Fahimi, F. G., & Karimi, D. (2009). Determination of environmentally sensitive zones along Persian Gulf coastlines through geographic information system. J. Food Agr. Environ, 7(2), 718-725.

Ornitz, B., & Champ, M. (Eds.). (2002). Oil spills first principles: prevention and best response. Elsevier.

Percy, R. J., LeBlanc, S. R., & Owens, E. H. (1997, April). An integrated approach to shoreline mapping for spill response planning in Canada. In International Oil Spill Conference (Vol. 1997, No. 1, pp. 277-288). American Petroleum Institute.

Pincinato, F. L., Riedel, P. S., & Milanelli, J. C. C. (2009). Modelling an expert GIS system based on knowledge to evaluate oil spill environmental sensitivity. Ocean & Coastal Management, 52(9), 479-486.

Pourvakhshouri, S. Z., & Mansor, S. (2003). Decision support system in oil spill cases (literature review). Disaster Prevention and Management, 12(3), 217-221.

Price, A. R. G., & Sheppard, C. R. C. (1991). The Gulf: Past, present and possible future states. Marine Pollution Bulletin, 22(5), 222-227.

Rogers, C.S. (1990). Response of corals and reef organisms to sedimentation. Marine Ecology. Prog. Ser. 62: 185–202.

Saenger, P. (1994). Cleaning up the Arabian Gulf: Aftermath of an oil spill. Search, 25, 19.

Souza Filho, P. W. M., Goncalves, F. D., de Miranda, F. P., Beisl, C. H., & de Faria Almeida, E. (2004, September). Environmental sensitivity mapping for oil spill in the Amazon coast using remote sensing and GIS technology. In Geoscience and Remote Sensing Symposium, 2004. IGARSS'04.

Souza-Filho, P. W. M., Goncalves, F. D., Rodrigues, S. W. P., Costa, F. R., & Miranda, F. P. (2009). Multi-sensor data fusion for geomorphological and environmental sensitivity index mapping in the Amazonian mangrove coast, Brazil. Journal of Coastal Research, 1592-1596

Szlafsztein, C., & Sterr, H. (2007). A GIS-based vulnerability assessment of coastal natural hazards, state of Pará, Brazil. Journal of Coastal Conservation, 11(1), 53-66.

Walker, D. A., Webber, P. J., Everett, K. R., & Brown, J. (1978). Effects of crude and diesel oil spills on plant communities at Prudhoe Bay, Alaska, and the derivation of oil spill sensitivity maps. Arctic, 242-259.

Wieczorek, A., Dias-Brito, D., & Milanelli, J. C. C. (2007). Mapping oil spill environmental sensitivity in Cardoso Island State Park and surroundings areas, São Paulo, Brazil. Ocean & Coastal Management, 50(11), 872-886.

Zirpolo, Alex. (2014). A Customized GIS Tool for Oil Spill Sensitivity Mapping. Proceeding of 2014 Esri User Conference. July 14–18, 2014 in San Diego, California.

# Appendices

Appendix A

Spatial Data for ArcGIS Analysis

a. Shoreline Type

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 1 | 40 | Sand | 3 | 16279.986 |
| 1 | 42 | Salt Marshes | 5 | 3489.089 |
| 1 | 43 | Salt Marshes | 5 | 8652.247 |
| 1 | 44 | Sand | 3 | 1783.343 |
| 1 | 45 | Rock | 2 | 5920.868 |
| 1 | 46 | Sand | 3 | 6978.304 |
| 1 | 47 | Salt Marshes | 5 | 802.622 |
| 1 | 48 | Sand | 3 | 12702.905 |
| 1 | 192 | Rock | 2 | 5602.166 |
| 2 | 48 | Sand | 3 | 12702.905 |
| 2 | 49 | Rock | 2 | 6728.572 |
| 2 | 50 | Sand | 3 | 7171.131 |
| 2 | 51 | Mangrove | 5 | 871.073 |
| 2 | 52 | Salt Marshes | 5 | 12083.530 |
| 2 | 53 | Rock | 2 | 288.442 |
| 2 | 54 | Sand | 3 | 1537.031 |
| 2 | 55 | Rock | 2 | 351.941 |
| 2 | 56 | Sand | 3 | 1301.820 |
| 3 | 34 | Sand | 3 | 1144.609 |
| 3 | 35 | Sand | 3 | 1941.273 |
| 3 | 36 | Sand | 3 | 1296.231 |
| 3 | 37 | Salt Marshes | 5 | 818.651 |
| 3 | 38 | Salt Marshes | 5 | 1674.780 |
| 3 | 39 | Sand | 3 | 863.537 |
| 3 | 57 | Rock | 2 | 1718.142 |
| 3 | 58 | Sand | 3 | 3087.280 |
| 3 | 59 | Rock | 2 | 3494.711 |
| 3 | 60 | Sand | 3 | 15674.045 |
| 3 | 61 | Salt Marshes | 5 | 2290.114 |
| 3 | 62 | Salt Marshes | 5 | 3178.146 |
| 3 | 63 | Sand | 3 | 3651.511 |
| 3 | 64 | Rock | 2 | 1663.011 |
| 4 | 30 | Sand | 3 | 516.621 |

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 4 | 31 | Rock | 2 | 855.724 |
| 4 | 32 | Rock | 2 | 1155.664 |
| 4 | 33 | Sand | 3 | 780.676 |
| 4 | 65 | Sand | 3 | 6619.475 |
| 4 | 66 | Rock | 2 | 879.138 |
| 4 | 67 | Sand | 3 | 28379.943 |
| 4 | 68 | Salt Marshes | 5 | 1332.331 |
| 4 | 69 | Rock | 2 | 3479.604 |
| 4 | 70 | Mud | 4 | 5348.164 |
| 4 | 71 | Sand | 3 | 1522.755 |
| 4 | 72 | Rock | 2 | 5806.157 |
| 4 | 73 | Sand | 3 | 7244.772 |
| 4 | 74 | Rock | 2 | 7163.884 |
| 4 | 75 | Salt Marshes | 5 | 1839.886 |
| 4 | 76 | Sand | 3 | 8744.808 |
| 4 | 77 | Mud | 4 | 1517.653 |
| 4 | 78 | Sand | 3 | 20920.376 |
| 4 | 79 | Mud | 4 | 9479.915 |
| 4 | 80 | Salt Marshes | 5 | 6477.841 |
| 5 | 25 | Salt Marshes | 5 | 676.788 |
| 5 | 26 | Salt Marshes | 5 | 1213.692 |
| 5 | 27 | Salt Marshes | 5 | 2629.465 |
| 5 | 28 | Salt Marshes | 5 | 150.221 |
| 5 | 29 | Salt Marshes | 5 | 563.871 |
| 5 | 79 | Mud | 4 | 9479.915 |
| 5 | 81 | Mud | 4 | 8730.034 |
| 5 | 82 | Salt Marshes | 5 | 751.088 |
| 5 | 83 | Mud | 4 | 1742.888 |
| 5 | 84 | Salt Marshes | 0 | 3041.050 |
| 5 | 85 | Sand | 3 | 1236.862 |
| 5 | 86 | Salt Marshes | 5 | 1122.333 |
| 5 | 87 | Sand | 3 | 1466.685 |
| 5 | 88 | Salt Marshes | 5 | 3905.839 |
| 5 | 89 | Mud | 4 | 1580.371 |
| 5 | 90 | Salt Marshes | 5 | 770.036 |
| 5 | 91 | Rock | 2 | 9112.077 |
| 5 | 92 | Salt Marshes | 5 | 16529.240 |
| 5 | 93 | Salt Marshes | 5 | 3152.065 |
| 5 | 94 | Salt Marshes | 5 | 5451.727 |
| 5 | 95 | Salt Marshes | 5 | 8868.165 |

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 5 | 96 | Sand | 3 | 10223.826 |
| 5 | 193 | Salt Marshes | 5 | 1532.647 |
| 5 | 194 | Salt Marshes | 5 | 689.834 |
| 5 | 195 | Mud | 4 | 1417.921 |
| 5 | 196 | Salt Marshes | 4 | 8606.467 |
| 5 | 197 | Mud | 4 | 5341.413 |
| 5 | 198 | Mud | 4 | 8013.123 |
| 6 | 24 | Mud | 4 | 1684.897 |
| 6 | 96 | Sand | 3 | 10223.826 |
| 6 | 97 | Rock | 2 | 4705.858 |
| 6 | 98 | Salt Marshes | 5 | 11138.004 |
| 6 | 99 | Sand | 3 | 29537.358 |
| 6 | 100 | Rock | 2 | 2457.298 |
| 7 | 101 | Sand | 3 | 37331.765 |
| 8 | 23 | Salt Marshes | 5 | 6927.642 |
| 8 | 103 | Sand | 3 | 4148.823 |
| 8 | 104 | Salt Marshes | 5 | 4112.858 |
| 8 | 105 | Salt Marshes | 4 | 5660.373 |
| 8 | 106 | Salt Marshes | 5 | 14394.450 |
| 8 | 107 | Sand | 3 | 6331.935 |
| 8 | 201 | Sand | 3 | 2126.243 |
| 8 | 202 | Salt Marshes | 5 | 281.806 |
| 8 | 203 | Mud | 4 | 3837.192 |
| 8 | 204 | Salt Marshes | 4 | 906.991 |
| 8 | 205 | Mud | 4 | 808.311 |
| 8 | 206 | Sand | 3 | 2578.799 |
| 9 | 22 | Sand | 3 | 12195.681 |
| 9 | 23 | Salt Marshes | 5 | 6927.642 |
| 9 | 102 | Salt Marshes | 5 | 10363.164 |
| 9 | 108 | Salt Marshes | 5 | 2626.414 |
| 9 | 109 | Sand | 3 | 6758.770 |
| 9 | 110 | Mud | 4 | 3651.324 |
| 9 | 111 | Salt Marshes | 5 | 4489.584 |
| 9 | 112 | Salt Marshes | 4 | 13140.755 |
| 9 | 113 | Salt Marshes | 5 | 5384.714 |
| 9 | 114 | Sand | 3 | 2613.839 |
| 9 | 115 | Mangrove | 5 | 427.015 |
| 9 | 116 | Sand | 3 | 3359.428 |
| 9 | 117 | Rock | 2 | 1070.585 |
| 9 | 118 | Salt Marshes | 5 | 7045.254 |

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 9 | 199 | Sand | 3 | 3312.635 |
| 9 | 200 | Salt Marshes | 5 | 1133.542 |
| 9 | 201 | Sand | 3 | 2126.243 |
| 9 | 206 | Sand | 3 | 2578.799 |
| 9 | 207 | Mud | 4 | 2404.492 |
| 9 | 208 | Salt Marshes | 5 | 1493.400 |
| 9 | 209 | Mud | 4 | 488.005 |
| 9 | 210 | Sand | 3 | 492.820 |
| 9 | 211 | Salt Marshes | 4 | 1468.756 |
| 10 | 135 | Sand | 5 | 54058.296 |
| 10 | 219 | Salt Marshes | 5 | 9133.714 |
| 10 | 220 | Sand | 5 | 992.536 |
| 10 | 221 | Salt Marshes | 5 | 6866.110 |
| 10 | 222 | Rock | 5 | 1365.695 |
| 10 | 223 | Salt Marshes | 5 | 6312.789 |
| 10 | 224 | Salt Marshes | 5 | 19098.801 |
| 10 | 225 | Salt Marshes | 5 | 6290.904 |
| 10 | 226 | Salt Marshes | 5 | 4304.437 |
| 10 | 227 | Sand | 3 | 773.629 |
| 10 | 228 | Sand | 3 | 4068.991 |
| 11 | 7 | Mangrove | 5 | 1006.955 |
| 11 | 8 | Mangrove | 5 | 630.735 |
| 11 | 9 | Mangrove | 5 | 2428.884 |
| 11 | 10 | Mangrove | 5 | 626.567 |
| 11 | 11 | Mangrove | 5 | 440.322 |
| 11 | 12 | Mangrove | 5 | 1189.504 |
| 11 | 13 | Mangrove | 5 | 593.374 |
| 11 | 14 | Mangrove | 5 | 1901.302 |
| 11 | 15 | Mangrove | 5 | 1179.925 |
| 11 | 17 | Sand | 3 | 2651.936 |
| 11 | 18 | Salt Marshes | 5 | 579.809 |
| 11 | 19 | Salt Marshes | 5 | 1855.488 |
| 11 | 20 | Salt Marshes | 5 | 11458.237 |
| 11 | 21 | Mud | 4 | 9709.743 |
| 11 | 118 | Salt Marshes | 5 | 7045.254 |
| 11 | 119 | Salt Marshes | 4 | 32629.566 |
| 11 | 120 | Sand | 3 | 3907.613 |
| 11 | 121 | Mangrove | 5 | 2460.359 |
| 11 | 122 | Salt Marshes | 5 | 5389.322 |
| 11 | 123 | Sand | 3 | 4807.638 |

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 11 | 124 | Salt Marshes | 5 | 1396.449 |
| 11 | 125 | Salt Marshes | 5 | 41264.385 |
| 11 | 126 | Salt Marshes | 5 | 2230.994 |
| 12 | 6 | Sand | 2 | 9225.765 |
| 12 | 16 | Mangrove | 5 | 13201.731 |
| 12 | 128 | Mud | 4 | 8991.401 |
| 12 | 129 | Rock | 2 | 730.895 |
| 12 | 130 | Mud | 4 | 1309.521 |
| 12 | 131 | Sand | 3 | 7440.440 |
| 12 | 132 | Salt Marshes | 4 | 2306.010 |
| 12 | 133 | Sand | 3 | 1946.057 |
| 12 | 136 | Salt Marshes | 5 | 2238.600 |
| 12 | 137 | Sand | 3 | 33325.030 |
| 12 | 138 | Salt Marshes | 5 | 4835.770 |
| 12 | 139 | Sand | 3 | 9366.852 |
| 12 | 140 | Rock | 2 | 21971.492 |
| 12 | 141 | Sand | 3 | 20020.239 |
| 12 | 142 | Rock | 2 | 23092.550 |
| 12 | 212 | Salt Marshes | 4 | 1132.878 |
| 12 | 213 | Mud | 4 | 1754.777 |
| 12 | 214 | Sand | 3 | 8104.487 |
| 12 | 215 | Salt Marshes | 3 | 5531.478 |
| 12 | 216 | Sand | 3 | 1196.947 |
| 12 | 217 | Salt Marshes | 3 | 2144.505 |
| 12 | 218 | Sand | 3 | 2510.697 |
| 12 | 219 | Salt Marshes | 5 | 9133.714 |
| 12 | 229 | Salt Marshes | 4 | 2374.437 |
| 12 | 230 | Mud | 4 | 3397.259 |
| 12 | 231 | Salt Marshes | 4 | 1735.986 |
| 13 | 6 | Sand | 2 | 9225.765 |
| 13 | 142 | Rock | 2 | 23092.550 |
| 13 | 143 | Sand | 3 | 17186.163 |
| 13 | 144 | Rock | 2 | 1602.430 |
| 13 | 145 | Sand | 3 | 15317.838 |
| 14 | 145 | Sand | 3 | 15317.838 |
| 14 | 146 | Rock | 2 | 19016.492 |
| 14 | 147 | Sand | 3 | 4858.628 |
| 14 | 148 | Rock | 2 | 8987.817 |
| 14 | 149 | Sand | 3 | 2726.387 |
| 14 | 150 | Sand | 3 | 48260.151 |

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 15 | 150 | Sand | 3 | 48260.151 |
| 16 | n/a | n/a | n/a | n/a |
| 17 | 4 | Mangrove | 5 | 1159.445 |
| 17 | 5 | Mangrove | 5 | 3249.383 |
| 17 | 150 | Sand | 3 | 48260.151 |
| 17 | 151 | Rock | 2 | 1563.173 |
| 17 | 152 | Sand | 3 | 7392.000 |
| 17 | 153 | Sand | 3 | 24881.227 |
| 17 | 154 | Salt Marshes | 5 | 7313.166 |
| 17 | 155 | Salt Marshes | 5 | 4049.346 |
| 17 | 156 | Rock | 2 | 5886.879 |
| 17 | 157 | Mud | 4 | 17526.945 |
| 17 | 158 | Sand | 3 | 902.413 |
| 17 | 159 | Rock | 2 | 2176.261 |
| 17 | 160 | Sand | 3 | 3592.620 |
| 17 | 161 | Sand | 3 | 635.185 |
| 17 | 162 | Mud | 4 | 726.464 |
| 17 | 163 | Salt Marshes | 5 | 13407.816 |
| 17 | 164 | Salt Marshes | 5 | 3560.132 |
| 17 | 165 | Salt Marshes | 5 | 2907.463 |
| 17 | 166 | Sand | 3 | 2379.455 |
| 17 | 167 | Mud | 4 | 1436.523 |
| 17 | 168 | Mangrove | 5 | 5944.823 |
| 17 | 169 | Rock | 2 | 6124.762 |
| 17 | 232 | Salt Marshes | 5 | 3774.205 |
| 18 | 0 | Armored | 1 | 4782.303 |
| 18 | 1 | Sand | 3 | 1893.461 |
| 18 | 2 | Mangrove | 5 | 1815.223 |
| 18 | 41 | Armored | 1 | 41838.667 |
| 18 | 169 | Rock | 2 | 6124.762 |
| 18 | 170 | Rock | 4 | 5481.308 |
| 18 | 171 | Mangrove | 5 | 6534.249 |
| 18 | 172 | Sand | 3 | 4379.292 |
| 18 | 173 | Salt Marshes | 5 | 7529.400 |
| 18 | 174 | Sand | 3 | 4162.836 |
| 18 | 175 | Mangrove | 5 | 1190.868 |
| 18 | 176 | Rock | 2 | 11228.665 |
| 18 | 177 | Sand | 3 | 4128.835 |
| 18 | 178 | Rock | 2 | 8381.431 |
| 18 | 179 | Sand | 3 | 1772.785 |

| Grid | FID | Attribute | ESI Score | Length (m) |
|---|---|---|---|---|
| 18 | 180 | Mangrove | 5 | 1193.220 |
| 18 | 181 | Sand | 3 | 551.215 |
| 18 | 182 | Mangrove | 5 | 2168.001 |
| 18 | 183 | Mud | 4 | 11030.957 |
| 18 | 184 | Sand | 3 | 5666.254 |
| 18 | 185 | Sand | 3 | 2638.597 |
| 18 | 186 | Sand | 3 | 17984.154 |
| 18 | 187 | Mud | 4 | 2918.984 |
| 18 | 188 | Mangrove | 5 | 1846.651 |
| 18 | 189 | Mud | 3 | 5247.523 |
| 18 | 190 | Sand | 3 | 18519.106 |
| 18 | 191 | Mud | 4 | 11389.913 |
| 18 | 232 | Salt Marshes | 5 | 3774.205 |
| 19 | 232 | Sand | 3 | 1713.962 |
| 19 | 232 | Salt Marshes | 5 | 842.982 |
| 19 | 232 | Sand | 3 | 757.564 |
| 19 | 232 | Salt Marshes | 5 | 1592.835 |
| 20 | 232 | Salt Marshes | 5 | 1304.157 |
| 20 | 232 | Salt Marshes | 5 | 1073.145 |
| 20 | 232 | Sand | 3 | 208.394 |
| 20 | 232 | Sand | 3 | 781.954 |
| 20 | 232 | Sand | 3 | 330.335 |

b. Biological Resources

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 1 | Corals | 39 | 415754.433 | 2946594.403 | 4 |
| 2 | Corals | 39 | 396869.919 | 2970649.589 | 4 |
| 3 | Corals | 39 | 372135.155 | 2983510.736 | 4 |
| 4 | Corals | 39 | 371762.172 | 2982956.502 | 4 |
| 5 | Corals | 39 | 371693.252 | 2982569.133 | 4 |
| 6 | Corals | 39 | 354559.978 | 3026730.103 | 4 |
| 7 | Corals | 39 | 369902.067 | 3021633.931 | 4 |
| 8 | Corals | 39 | 371527.462 | 3019860.358 | 4 |
| 9 | Corals | 39 | 368729.727 | 3019972.365 | 4 |
| 10 | Corals | 39 | 369406.352 | 3019895.406 | 4 |
| 11 | Corals | 39 | 370495.557 | 3019931.076 | 4 |
| 12 | Corals | 39 | 340670.343 | 3029521.467 | 4 |
| 13 | Corals | 39 | 339099.099 | 3025894.053 | 4 |
| 14 | Corals | 39 | 336022.623 | 3025098.029 | 4 |
| 15 | Corals | 39 | 345390.601 | 3025001.433 | 4 |
| 16 | Corals | 39 | 344019.917 | 3022627.654 | 4 |
| 17 | Corals | 39 | 340911.655 | 3023500.257 | 4 |
| 18 | Corals | 39 | 340881.019 | 3023222.464 | 4 |
| 19 | Corals | 39 | 340724.452 | 3023378.891 | 4 |
| 20 | Corals | 39 | 342438.560 | 3023139.493 | 4 |
| 21 | Corals | 39 | 342263.349 | 3023053.840 | 4 |
| 22 | Corals | 39 | 343043.363 | 3018482.445 | 4 |
| 23 | Corals | 39 | 344349.516 | 3016025.161 | 4 |
| 24 | Corals | 39 | 348073.314 | 3006543.798 | 4 |
| 25 | Corals | 39 | 351985.305 | 3010387.543 | 4 |
| 26 | Corals | 39 | 348654.673 | 3027436.094 | 4 |
| 27 | Corals | 39 | 347793.733 | 3026926.962 | 4 |
| 28 | Corals | 39 | 348318.331 | 3025602.375 | 4 |
| 29 | Corals | 39 | 349291.616 | 3024811.270 | 4 |
| 30 | Corals | 39 | 349743.290 | 3025212.087 | 4 |
| 31 | Corals | 39 | 352738.855 | 3026206.946 | 4 |
| 32 | Corals | 39 | 351680.923 | 3026049.078 | 4 |
| 33 | Corals | 39 | 350675.157 | 3026171.553 | 4 |
| 34 | Corals | 39 | 349886.607 | 3025528.331 | 4 |
| 35 | Corals | 39 | 349997.940 | 3025404.813 | 4 |
| 36 | Corals | 39 | 347251.795 | 3021941.446 | 4 |
| 37 | Corals | 39 | 329852.997 | 3033180.317 | 4 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 38 | Corals | 39 | 329978.635 | 3041771.310 | 4 |
| 39 | Corals | 39 | 348534.956 | 3023207.048 | 4 |
| 40 | Corals | 39 | 300627.638 | 3085984.606 | 4 |
| 41 | Corals | 39 | 300681.863 | 3085650.727 | 4 |
| 42 | Corals | 39 | 300693.663 | 3085138.304 | 4 |
| 43 | Corals | 39 | 300977.531 | 3085367.009 | 4 |
| 44 | Corals | 39 | 300423.510 | 3085566.861 | 4 |
| 45 | Corals | 39 | 287238.681 | 3095469.670 | 4 |
| 46 | Corals | 39 | 279170.813 | 3096287.211 | 4 |
| 47 | Corals | 39 | 280417.963 | 3095766.827 | 4 |
| 48 | Corals | 39 | 280041.727 | 3095443.802 | 4 |
| 49 | Corals | 39 | 280280.607 | 3095520.939 | 4 |
| 50 | Corals | 39 | 280715.551 | 3095331.802 | 4 |
| 51 | Corals | 39 | 281967.958 | 3096009.025 | 4 |
| 52 | Corals | 39 | 291250.743 | 3066762.514 | 4 |
| 53 | Corals | 39 | 290682.900 | 3068342.135 | 4 |
| 54 | Corals | 39 | 295206.750 | 3081874.097 | 4 |
| 55 | Corals | 39 | 295032.566 | 3056477.868 | 4 |
| 56 | Corals | 39 | 294301.345 | 3055476.372 | 4 |
| 57 | Corals | 39 | 294318.900 | 3055194.880 | 4 |
| 58 | Corals | 39 | 293648.263 | 3054193.422 | 4 |
| 59 | Corals | 39 | 301180.770 | 3057547.494 | 4 |
| 60 | Corals | 39 | 304163.711 | 3056866.408 | 4 |
| 61 | Corals | 39 | 304118.929 | 3055147.784 | 4 |
| 62 | Corals | 39 | 304488.607 | 3054846.488 | 4 |
| 63 | Corals | 39 | 304982.945 | 3054362.147 | 4 |
| 64 | Corals | 39 | 305554.960 | 3053980.644 | 4 |
| 65 | Corals | 39 | 312453.064 | 3049568.554 | 4 |
| 66 | Corals | 39 | 311235.263 | 3049433.105 | 4 |
| 67 | Corals | 39 | 322247.203 | 3049071.042 | 4 |
| 68 | Corals | 39 | 322754.619 | 3051384.206 | 4 |
| 69 | Corals | 39 | 321237.290 | 3053632.765 | 4 |
| 70 | Corals | 39 | 314109.695 | 3048527.279 | 4 |
| 71 | Corals | 39 | 308372.153 | 3051953.883 | 4 |
| 72 | Corals | 39 | 307287.626 | 3057758.829 | 4 |
| 73 | Corals | 39 | 306539.682 | 3059304.784 | 4 |
| 74 | Corals | 39 | 303032.911 | 3060734.899 | 4 |
| 75 | Corals | 39 | 306057.716 | 3060628.297 | 4 |
| 76 | Corals | 39 | 306030.769 | 3061207.115 | 4 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 77 | Corals | 39 | 305530.802 | 3062594.808 | 4 |
| 78 | Corals | 39 | 310292.886 | 3061280.229 | 4 |
| 79 | Corals | 39 | 310401.480 | 3061915.255 | 4 |
| 80 | Corals | 39 | 296282.545 | 3063974.882 | 4 |
| 81 | Corals | 39 | 266698.976 | 3114976.879 | 4 |
| 82 | Corals | 39 | 284463.746 | 3117845.641 | 4 |
| 83 | Corals | 39 | 280986.135 | 3117510.079 | 4 |
| 84 | Corals | 39 | 280657.066 | 3111268.878 | 4 |
| 85 | Corals | 39 | 277194.865 | 3108659.817 | 4 |
| 86 | Corals | 39 | 289977.055 | 3110809.848 | 4 |
| 87 | Corals | 39 | 294487.030 | 3108687.684 | 4 |
| 88 | Corals | 39 | 281673.329 | 3099997.164 | 4 |
| 89 | Corals | 39 | 283466.552 | 3101442.294 | 4 |
| 90 | Corals | 39 | 283756.220 | 3103693.675 | 4 |
| 91 | Corals | 39 | 276989.705 | 3100881.731 | 4 |
| 92 | Corals | 39 | 267899.880 | 3111364.339 | 4 |
| 93 | Corals | 39 | 269300.673 | 3111815.362 | 4 |
| 94 | Corals | 39 | 272812.046 | 3111937.782 | 4 |
| 95 | Corals | 39 | 274159.069 | 3113538.471 | 4 |
| 96 | Corals | 39 | 266136.320 | 3114697.069 | 4 |
| 97 | Corals | 39 | 273352.685 | 3118974.388 | 4 |
| 98 | Corals | 39 | 271251.977 | 3126222.235 | 4 |
| 99 | Corals | 39 | 265133.978 | 3126273.821 | 4 |
| 100 | Corals | 39 | 265553.844 | 3126069.467 | 4 |
| 101 | Corals | 39 | 262648.856 | 3130771.264 | 4 |
| 102 | Corals | 39 | 261886.025 | 3132908.354 | 4 |
| 103 | Corals | 39 | 263172.625 | 3136446.050 | 4 |
| 104 | Corals | 39 | 258530.343 | 3140883.546 | 4 |
| 105 | Corals | 39 | 257034.966 | 3139727.573 | 4 |
| 107 | Corals | 39 | 265903.651 | 3112680.414 | 4 |
| 108 | Corals | 39 | 266262.523 | 3113005.452 | 4 |
| 109 | Corals | 39 | 266514.574 | 3111886.309 | 4 |
| 110 | Corals | 39 | 265801.020 | 3111927.785 | 4 |
| 111 | Corals | 39 | 290778.273 | 3119044.589 | 4 |
| 112 | Corals | 39 | 353773.727 | 3026590.899 | 4 |
| 113 | Seagrass | 39 | 423204.124 | 2919995.710 | 3 |
| 114 | Seagrass | 39 | 423684.261 | 2920896.035 | 3 |
| 115 | Seagrass | 39 | 423383.521 | 2918234.662 | 3 |
| 116 | Seagrass | 39 | 423705.881 | 2918617.594 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 117 | Seagrass | 39 | 422594.282 | 2918199.145 | 3 |
| 118 | Seagrass | 39 | 420271.500 | 2922277.681 | 3 |
| 119 | Seagrass | 39 | 419824.569 | 2923745.119 | 3 |
| 120 | Seagrass | 39 | 419976.642 | 2924463.122 | 3 |
| 121 | Seagrass | 39 | 422414.823 | 2922646.084 | 3 |
| 122 | Seagrass | 39 | 421741.915 | 2922225.319 | 3 |
| 123 | Seagrass | 39 | 420221.902 | 2926536.955 | 3 |
| 124 | Seagrass | 39 | 422297.256 | 2926649.656 | 3 |
| 125 | Seagrass | 39 | 421164.778 | 2927372.103 | 3 |
| 126 | Seagrass | 39 | 420303.174 | 2925384.927 | 3 |
| 127 | Seagrass | 39 | 423757.380 | 2926636.200 | 3 |
| 128 | Seagrass | 39 | 421051.410 | 2924301.094 | 3 |
| 129 | Seagrass | 39 | 419728.041 | 2922519.924 | 3 |
| 130 | Seagrass | 39 | 415061.232 | 2927009.430 | 3 |
| 131 | Seagrass | 39 | 416176.906 | 2929152.119 | 3 |
| 132 | Seagrass | 39 | 416223.057 | 2928278.566 | 3 |
| 133 | Seagrass | 39 | 415787.290 | 2928608.200 | 3 |
| 134 | Seagrass | 39 | 416063.916 | 2927187.229 | 3 |
| 135 | Seagrass | 39 | 415321.098 | 2926078.768 | 3 |
| 136 | Seagrass | 39 | 414876.631 | 2925722.925 | 3 |
| 137 | Seagrass | 39 | 415642.316 | 2926528.088 | 3 |
| 138 | Seagrass | 39 | 407225.277 | 2930130.438 | 3 |
| 139 | Seagrass | 39 | 411973.713 | 2930586.943 | 3 |
| 140 | Seagrass | 39 | 412478.852 | 2930945.998 | 3 |
| 141 | Seagrass | 39 | 423916.992 | 2930276.642 | 3 |
| 142 | Seagrass | 39 | 423635.348 | 2930698.252 | 3 |
| 143 | Seagrass | 39 | 409109.892 | 2932580.657 | 3 |
| 144 | Seagrass | 39 | 406507.270 | 2936033.658 | 3 |
| 145 | Seagrass | 39 | 408846.877 | 2936845.143 | 3 |
| 146 | Seagrass | 39 | 409466.472 | 2937544.528 | 3 |
| 147 | Seagrass | 39 | 412437.444 | 2938319.111 | 3 |
| 148 | Seagrass | 39 | 411849.983 | 2941511.621 | 3 |
| 149 | Seagrass | 39 | 409139.088 | 2942219.482 | 3 |
| 150 | Seagrass | 39 | 408809.024 | 2942069.538 | 3 |
| 151 | Seagrass | 39 | 408752.915 | 2942453.052 | 3 |
| 152 | Seagrass | 39 | 405256.230 | 2942784.357 | 3 |
| 153 | Seagrass | 39 | 406287.514 | 2942656.580 | 3 |
| 154 | Seagrass | 39 | 410895.229 | 2942477.254 | 3 |
| 155 | Seagrass | 39 | 411936.433 | 2942271.429 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 156 | Seagrass | 39 | 406339.093 | 2943274.788 | 3 |
| 157 | Seagrass | 39 | 412469.573 | 2942976.784 | 3 |
| 158 | Seagrass | 39 | 403781.517 | 2943488.207 | 3 |
| 159 | Seagrass | 39 | 401689.236 | 2942168.824 | 3 |
| 160 | Seagrass | 39 | 411383.972 | 2938368.229 | 3 |
| 161 | Seagrass | 39 | 413694.279 | 2939118.754 | 3 |
| 162 | Seagrass | 39 | 414129.231 | 2940220.812 | 3 |
| 163 | Seagrass | 39 | 416354.959 | 2942136.053 | 3 |
| 164 | Seagrass | 39 | 407922.652 | 2933024.159 | 3 |
| 165 | Seagrass | 39 | 414825.312 | 2941185.179 | 3 |
| 166 | Seagrass | 39 | 414691.593 | 2936185.631 | 3 |
| 167 | Seagrass | 39 | 415319.736 | 2945070.026 | 3 |
| 168 | Seagrass | 39 | 412787.298 | 2933623.705 | 3 |
| 169 | Seagrass | 39 | 407699.439 | 2933893.255 | 3 |
| 170 | Seagrass | 39 | 409399.874 | 2936326.927 | 3 |
| 171 | Seagrass | 39 | 410220.430 | 2939768.085 | 3 |
| 172 | Seagrass | 39 | 411536.551 | 2934759.073 | 3 |
| 173 | Seagrass | 39 | 409894.778 | 2932527.349 | 3 |
| 174 | Seagrass | 39 | 412915.498 | 2939682.808 | 3 |
| 175 | Seagrass | 39 | 413986.520 | 2935725.645 | 3 |
| 176 | Seagrass | 39 | 414000.859 | 2938237.468 | 3 |
| 177 | Seagrass | 39 | 410699.451 | 2935510.643 | 3 |
| 178 | Seagrass | 39 | 407247.062 | 2933220.964 | 3 |
| 179 | Seagrass | 39 | 412353.736 | 2933901.243 | 3 |
| 180 | Seagrass | 39 | 410148.715 | 2934434.106 | 3 |
| 181 | Seagrass | 39 | 410810.071 | 2939021.964 | 3 |
| 182 | Seagrass | 39 | 410004.980 | 2937154.022 | 3 |
| 183 | Seagrass | 39 | 411660.333 | 2940392.599 | 3 |
| 184 | Seagrass | 39 | 407961.742 | 2935216.229 | 3 |
| 185 | Seagrass | 39 | 410523.160 | 2936727.276 | 3 |
| 186 | Seagrass | 39 | 417306.020 | 2945379.627 | 3 |
| 187 | Seagrass | 39 | 415696.935 | 2948397.720 | 3 |
| 188 | Seagrass | 39 | 417584.980 | 2948599.008 | 3 |
| 189 | Seagrass | 39 | 415848.443 | 2948783.858 | 3 |
| 190 | Seagrass | 39 | 417600.696 | 2949024.006 | 3 |
| 191 | Seagrass | 39 | 399579.281 | 2949671.583 | 3 |
| 192 | Seagrass | 39 | 415553.796 | 2950891.070 | 3 |
| 193 | Seagrass | 39 | 414731.564 | 2950860.804 | 3 |
| 194 | Seagrass | 39 | 414445.403 | 2951362.895 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 195 | Seagrass | 39 | 414740.889 | 2952275.173 | 3 |
| 196 | Seagrass | 39 | 413851.394 | 2952840.209 | 3 |
| 197 | Seagrass | 39 | 412111.263 | 2953153.291 | 3 |
| 198 | Seagrass | 39 | 411700.459 | 2953129.838 | 3 |
| 199 | Seagrass | 39 | 413391.560 | 2953710.178 | 3 |
| 200 | Seagrass | 39 | 411474.744 | 2953849.602 | 3 |
| 201 | Seagrass | 39 | 411842.294 | 2953882.681 | 3 |
| 202 | Seagrass | 39 | 410665.161 | 2955850.559 | 3 |
| 203 | Seagrass | 39 | 412312.595 | 2946255.013 | 3 |
| 204 | Seagrass | 39 | 401251.833 | 2955852.882 | 3 |
| 205 | Seagrass | 39 | 410056.823 | 2943119.698 | 3 |
| 206 | Seagrass | 39 | 403131.487 | 2951769.378 | 3 |
| 207 | Seagrass | 39 | 400017.395 | 2953525.793 | 3 |
| 208 | Seagrass | 39 | 404068.906 | 2947472.322 | 3 |
| 209 | Seagrass | 39 | 414060.538 | 2947241.253 | 3 |
| 210 | Seagrass | 39 | 405014.104 | 2947116.222 | 3 |
| 211 | Seagrass | 39 | 415465.464 | 2945858.118 | 3 |
| 212 | Seagrass | 39 | 403099.535 | 2945176.249 | 3 |
| 213 | Seagrass | 39 | 408699.960 | 2943173.808 | 3 |
| 214 | Seagrass | 39 | 411753.044 | 2948421.684 | 3 |
| 215 | Seagrass | 39 | 401069.703 | 2949574.973 | 3 |
| 216 | Seagrass | 39 | 405423.583 | 2948252.237 | 3 |
| 217 | Seagrass | 39 | 403726.409 | 2945273.457 | 3 |
| 218 | Seagrass | 39 | 405888.586 | 2949751.101 | 3 |
| 219 | Seagrass | 39 | 402627.630 | 2952009.659 | 3 |
| 220 | Seagrass | 39 | 403296.065 | 2947269.855 | 3 |
| 221 | Seagrass | 39 | 402562.420 | 2947269.390 | 3 |
| 222 | Seagrass | 39 | 413298.043 | 2948970.918 | 3 |
| 223 | Seagrass | 39 | 402799.920 | 2948748.999 | 3 |
| 224 | Seagrass | 39 | 408658.471 | 2944775.572 | 3 |
| 225 | Seagrass | 39 | 412765.042 | 2945298.653 | 3 |
| 226 | Seagrass | 39 | 409491.726 | 2948479.886 | 3 |
| 227 | Seagrass | 39 | 406312.524 | 2950171.346 | 3 |
| 228 | Seagrass | 39 | 401028.671 | 2953697.123 | 3 |
| 229 | Seagrass | 39 | 410936.595 | 2949282.374 | 3 |
| 230 | Seagrass | 39 | 412694.665 | 2949072.522 | 3 |
| 231 | Seagrass | 39 | 405929.731 | 2946870.109 | 3 |
| 232 | Seagrass | 39 | 411198.576 | 2946325.668 | 3 |
| 233 | Seagrass | 39 | 411248.897 | 2945358.858 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 234 | Seagrass | 39 | 406757.640 | 2944974.950 | 3 |
| 235 | Seagrass | 39 | 401850.958 | 2954013.584 | 3 |
| 236 | Seagrass | 39 | 406577.752 | 2948764.975 | 3 |
| 237 | Seagrass | 39 | 408272.968 | 2943434.403 | 3 |
| 238 | Seagrass | 39 | 409823.177 | 2945760.700 | 3 |
| 239 | Seagrass | 39 | 401968.832 | 2952442.643 | 3 |
| 240 | Seagrass | 39 | 412050.998 | 2947635.263 | 3 |
| 241 | Seagrass | 39 | 403100.422 | 2950521.933 | 3 |
| 242 | Seagrass | 39 | 407171.239 | 2947517.868 | 3 |
| 243 | Seagrass | 39 | 402640.688 | 2944097.464 | 3 |
| 244 | Seagrass | 39 | 413060.092 | 2944576.760 | 3 |
| 245 | Seagrass | 39 | 404169.168 | 2945958.132 | 3 |
| 246 | Seagrass | 39 | 408811.443 | 2948215.383 | 3 |
| 247 | Seagrass | 39 | 405575.864 | 2944373.110 | 3 |
| 248 | Seagrass | 39 | 410361.940 | 2956894.915 | 3 |
| 249 | Seagrass | 39 | 408366.157 | 2958122.938 | 3 |
| 250 | Seagrass | 39 | 406264.634 | 2959283.507 | 3 |
| 251 | Seagrass | 39 | 406548.682 | 2959936.639 | 3 |
| 252 | Seagrass | 39 | 405751.021 | 2962123.789 | 3 |
| 253 | Seagrass | 39 | 404403.019 | 2963468.854 | 3 |
| 254 | Seagrass | 39 | 402910.683 | 2964009.780 | 3 |
| 255 | Seagrass | 39 | 401796.444 | 2965129.984 | 3 |
| 256 | Seagrass | 39 | 399481.603 | 2967826.386 | 3 |
| 257 | Seagrass | 39 | 399441.497 | 2968264.759 | 3 |
| 258 | Seagrass | 39 | 398941.947 | 2968654.620 | 3 |
| 259 | Seagrass | 39 | 346853.745 | 3001741.038 | 3 |
| 260 | Seagrass | 39 | 349181.458 | 3004843.561 | 3 |
| 261 | Seagrass | 39 | 350466.967 | 3004765.251 | 3 |
| 262 | Seagrass | 39 | 349018.225 | 3005402.067 | 3 |
| 263 | Seagrass | 39 | 349727.049 | 3006448.988 | 3 |
| 264 | Seagrass | 39 | 350629.197 | 3005560.694 | 3 |
| 265 | Seagrass | 39 | 350593.803 | 3006786.643 | 3 |
| 266 | Seagrass | 39 | 347770.807 | 3007661.367 | 3 |
| 267 | Seagrass | 39 | 346439.231 | 3008504.524 | 3 |
| 268 | Seagrass | 39 | 350810.528 | 3007997.878 | 3 |
| 269 | Seagrass | 39 | 345549.312 | 3009018.078 | 3 |
| 270 | Seagrass | 39 | 359199.573 | 3008755.407 | 3 |
| 271 | Seagrass | 39 | 359897.455 | 3009043.196 | 3 |
| 272 | Seagrass | 39 | 359245.193 | 3009082.654 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 273 | Seagrass | 39 | 357066.744 | 3009691.853 | 3 |
| 274 | Seagrass | 39 | 339090.401 | 3010597.458 | 3 |
| 275 | Seagrass | 39 | 358276.762 | 3008613.833 | 3 |
| 276 | Seagrass | 39 | 358434.289 | 3007912.841 | 3 |
| 277 | Seagrass | 39 | 356888.887 | 3007304.074 | 3 |
| 278 | Seagrass | 39 | 349014.000 | 3010443.328 | 3 |
| 279 | Seagrass | 39 | 358683.184 | 3010775.322 | 3 |
| 280 | Seagrass | 39 | 360126.946 | 3012055.394 | 3 |
| 281 | Seagrass | 39 | 337092.426 | 3013279.053 | 3 |
| 282 | Seagrass | 39 | 334639.637 | 3013864.564 | 3 |
| 283 | Seagrass | 39 | 334096.662 | 3014525.002 | 3 |
| 284 | Seagrass | 39 | 358158.348 | 3013094.170 | 3 |
| 285 | Seagrass | 39 | 358361.091 | 3012150.934 | 3 |
| 286 | Seagrass | 39 | 359560.681 | 3012866.374 | 3 |
| 287 | Seagrass | 39 | 360671.301 | 3013062.235 | 3 |
| 288 | Seagrass | 39 | 359586.615 | 3011140.353 | 3 |
| 289 | Seagrass | 39 | 359906.595 | 3013755.563 | 3 |
| 290 | Seagrass | 39 | 356945.183 | 3014376.639 | 3 |
| 291 | Seagrass | 39 | 353792.958 | 3014729.870 | 3 |
| 292 | Seagrass | 39 | 353166.845 | 3014461.085 | 3 |
| 293 | Seagrass | 39 | 353327.010 | 3015377.442 | 3 |
| 294 | Seagrass | 39 | 359255.502 | 3015001.883 | 3 |
| 295 | Seagrass | 39 | 358745.073 | 3014483.639 | 3 |
| 296 | Seagrass | 39 | 358060.174 | 3015005.399 | 3 |
| 297 | Seagrass | 39 | 356416.464 | 3017945.626 | 3 |
| 298 | Seagrass | 39 | 356963.670 | 3018581.531 | 3 |
| 299 | Seagrass | 39 | 344198.743 | 3016383.462 | 3 |
| 300 | Seagrass | 39 | 341724.523 | 3018006.417 | 3 |
| 301 | Seagrass | 39 | 345410.751 | 3015663.782 | 3 |
| 302 | Seagrass | 39 | 343555.577 | 3016267.827 | 3 |
| 303 | Seagrass | 39 | 345589.843 | 3015003.871 | 3 |
| 304 | Seagrass | 39 | 347316.794 | 3017080.464 | 3 |
| 305 | Seagrass | 39 | 344937.931 | 3016015.295 | 3 |
| 306 | Seagrass | 39 | 344799.904 | 3015442.855 | 3 |
| 307 | Seagrass | 39 | 351453.054 | 3019050.395 | 3 |
| 308 | Seagrass | 39 | 346998.345 | 3019683.437 | 3 |
| 309 | Seagrass | 39 | 356490.646 | 3019022.925 | 3 |
| 310 | Seagrass | 39 | 354720.437 | 3016093.574 | 3 |
| 311 | Seagrass | 39 | 354843.232 | 3019786.990 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 312 | Seagrass | 39 | 354724.618 | 3015095.220 | 3 |
| 313 | Seagrass | 39 | 354407.949 | 3019022.377 | 3 |
| 314 | Seagrass | 39 | 352985.100 | 3019146.097 | 3 |
| 315 | Seagrass | 39 | 356654.296 | 3019561.986 | 3 |
| 316 | Seagrass | 39 | 353782.113 | 3018566.964 | 3 |
| 317 | Seagrass | 39 | 353208.028 | 3017732.388 | 3 |
| 318 | Seagrass | 39 | 346876.283 | 3020726.262 | 3 |
| 319 | Seagrass | 39 | 347311.183 | 3021034.841 | 3 |
| 320 | Seagrass | 39 | 341498.277 | 3020297.007 | 3 |
| 321 | Seagrass | 39 | 341818.046 | 3021354.518 | 3 |
| 322 | Seagrass | 39 | 347429.508 | 3021616.026 | 3 |
| 323 | Seagrass | 39 | 347565.339 | 3022341.373 | 3 |
| 324 | Seagrass | 39 | 366867.533 | 3022412.423 | 3 |
| 325 | Seagrass | 39 | 366437.679 | 3022364.325 | 3 |
| 326 | Seagrass | 39 | 352137.602 | 3022872.509 | 3 |
| 327 | Seagrass | 39 | 351915.064 | 3021085.362 | 3 |
| 328 | Seagrass | 39 | 355843.882 | 3023359.113 | 3 |
| 329 | Seagrass | 39 | 335226.781 | 3021306.710 | 3 |
| 330 | Seagrass | 39 | 335221.379 | 3021947.476 | 3 |
| 331 | Seagrass | 39 | 336672.577 | 3020999.303 | 3 |
| 332 | Seagrass | 39 | 336408.393 | 3021923.333 | 3 |
| 333 | Seagrass | 39 | 337701.485 | 3019227.743 | 3 |
| 334 | Seagrass | 39 | 338491.467 | 3021608.857 | 3 |
| 335 | Seagrass | 39 | 338296.292 | 3015735.494 | 3 |
| 336 | Seagrass | 39 | 334778.804 | 3021630.068 | 3 |
| 337 | Seagrass | 39 | 336533.403 | 3023479.913 | 3 |
| 338 | Seagrass | 39 | 335689.335 | 3022431.389 | 3 |
| 339 | Seagrass | 39 | 339112.526 | 3017250.349 | 3 |
| 340 | Seagrass | 39 | 335766.372 | 3024680.315 | 3 |
| 341 | Seagrass | 39 | 365220.954 | 3022937.947 | 3 |
| 342 | Seagrass | 39 | 353213.944 | 3021299.511 | 3 |
| 343 | Seagrass | 39 | 355225.752 | 3022246.784 | 3 |
| 344 | Seagrass | 39 | 354445.809 | 3022757.043 | 3 |
| 345 | Seagrass | 39 | 364257.028 | 3024224.377 | 3 |
| 346 | Seagrass | 39 | 333981.716 | 3025900.854 | 3 |
| 347 | Seagrass | 39 | 329651.592 | 3026281.952 | 3 |
| 348 | Seagrass | 39 | 363820.543 | 3024783.705 | 3 |
| 349 | Seagrass | 39 | 339022.849 | 3025245.225 | 3 |
| 350 | Seagrass | 39 | 339320.979 | 3024686.540 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 351 | Seagrass | 39 | 365320.052 | 3024184.703 | 3 |
| 352 | Seagrass | 39 | 332191.932 | 3026315.260 | 3 |
| 353 | Seagrass | 39 | 330294.637 | 3026461.246 | 3 |
| 354 | Seagrass | 39 | 362446.011 | 3024543.839 | 3 |
| 355 | Seagrass | 39 | 364232.926 | 3024829.317 | 3 |
| 356 | Seagrass | 39 | 330430.332 | 3026572.326 | 3 |
| 357 | Seagrass | 39 | 332506.601 | 3026843.024 | 3 |
| 358 | Seagrass | 39 | 332258.378 | 3026728.393 | 3 |
| 359 | Seagrass | 39 | 329274.304 | 3026932.333 | 3 |
| 360 | Seagrass | 39 | 347713.029 | 3026132.839 | 3 |
| 361 | Seagrass | 39 | 360490.398 | 3025764.665 | 3 |
| 362 | Seagrass | 39 | 348280.450 | 3026933.700 | 3 |
| 363 | Seagrass | 39 | 347023.751 | 3025804.179 | 3 |
| 364 | Seagrass | 39 | 354427.200 | 3027255.257 | 3 |
| 365 | Seagrass | 39 | 358785.545 | 3027040.983 | 3 |
| 366 | Seagrass | 39 | 362680.006 | 3027058.998 | 3 |
| 367 | Seagrass | 39 | 356410.238 | 3027810.496 | 3 |
| 368 | Seagrass | 39 | 323710.622 | 3029996.764 | 3 |
| 369 | Seagrass | 39 | 340075.347 | 3028663.926 | 3 |
| 370 | Seagrass | 39 | 323102.592 | 3030601.068 | 3 |
| 371 | Seagrass | 39 | 323937.828 | 3030777.846 | 3 |
| 372 | Seagrass | 39 | 322634.244 | 3030976.892 | 3 |
| 373 | Seagrass | 39 | 322899.258 | 3031103.799 | 3 |
| 374 | Seagrass | 39 | 322696.661 | 3031437.022 | 3 |
| 375 | Seagrass | 39 | 322896.506 | 3031826.560 | 3 |
| 376 | Seagrass | 39 | 321669.709 | 3031919.384 | 3 |
| 377 | Seagrass | 39 | 322780.192 | 3032137.378 | 3 |
| 378 | Seagrass | 39 | 338870.983 | 3031769.514 | 3 |
| 379 | Seagrass | 39 | 338390.764 | 3032328.386 | 3 |
| 380 | Seagrass | 39 | 323180.751 | 3032367.061 | 3 |
| 381 | Seagrass | 39 | 338825.903 | 3032451.820 | 3 |
| 382 | Seagrass | 39 | 329454.308 | 3033336.002 | 3 |
| 383 | Seagrass | 39 | 329648.763 | 3033647.117 | 3 |
| 384 | Seagrass | 39 | 330151.914 | 3033642.045 | 3 |
| 385 | Seagrass | 39 | 339035.793 | 3033512.112 | 3 |
| 386 | Seagrass | 39 | 335716.330 | 3033824.756 | 3 |
| 387 | Seagrass | 39 | 329874.238 | 3033966.316 | 3 |
| 388 | Seagrass | 39 | 339549.934 | 3033835.324 | 3 |
| 389 | Seagrass | 39 | 336050.793 | 3033781.022 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 390 | Seagrass | 39 | 338978.863 | 3033974.781 | 3 |
| 391 | Seagrass | 39 | 334786.500 | 3034697.919 | 3 |
| 392 | Seagrass | 39 | 336421.436 | 3034736.057 | 3 |
| 393 | Seagrass | 39 | 335995.265 | 3034759.477 | 3 |
| 394 | Seagrass | 39 | 332641.330 | 3035215.164 | 3 |
| 395 | Seagrass | 39 | 336793.449 | 3035021.936 | 3 |
| 396 | Seagrass | 39 | 333928.094 | 3035038.728 | 3 |
| 397 | Seagrass | 39 | 334681.338 | 3035535.851 | 3 |
| 398 | Seagrass | 39 | 336433.835 | 3035488.576 | 3 |
| 399 | Seagrass | 39 | 337823.912 | 3035612.260 | 3 |
| 400 | Seagrass | 39 | 335250.096 | 3035805.601 | 3 |
| 401 | Seagrass | 39 | 334575.417 | 3035948.668 | 3 |
| 402 | Seagrass | 39 | 334723.524 | 3036329.517 | 3 |
| 403 | Seagrass | 39 | 332449.533 | 3033591.596 | 3 |
| 404 | Seagrass | 39 | 327035.543 | 3027161.592 | 3 |
| 405 | Seagrass | 39 | 326622.468 | 3027743.891 | 3 |
| 406 | Seagrass | 39 | 323227.518 | 3035263.825 | 3 |
| 407 | Seagrass | 39 | 329277.585 | 3029958.192 | 3 |
| 408 | Seagrass | 39 | 331367.064 | 3034790.106 | 3 |
| 409 | Seagrass | 39 | 322729.560 | 3033882.025 | 3 |
| 410 | Seagrass | 39 | 320642.707 | 3032598.951 | 3 |
| 411 | Seagrass | 39 | 331741.729 | 3032065.360 | 3 |
| 412 | Seagrass | 39 | 317188.779 | 3034744.297 | 3 |
| 413 | Seagrass | 39 | 322667.416 | 3034559.339 | 3 |
| 414 | Seagrass | 39 | 327619.639 | 3028024.624 | 3 |
| 415 | Seagrass | 39 | 333722.309 | 3033836.979 | 3 |
| 416 | Seagrass | 39 | 328170.413 | 3035408.020 | 3 |
| 417 | Seagrass | 39 | 327986.434 | 3033885.702 | 3 |
| 418 | Seagrass | 39 | 330665.089 | 3031987.258 | 3 |
| 419 | Seagrass | 39 | 319882.776 | 3032868.219 | 3 |
| 420 | Seagrass | 39 | 325989.714 | 3033043.110 | 3 |
| 421 | Seagrass | 39 | 322520.658 | 3033149.069 | 3 |
| 422 | Seagrass | 39 | 329006.116 | 3034304.742 | 3 |
| 423 | Seagrass | 39 | 331284.794 | 3031848.743 | 3 |
| 424 | Seagrass | 39 | 327266.730 | 3032709.793 | 3 |
| 425 | Seagrass | 39 | 324601.989 | 3034360.039 | 3 |
| 426 | Seagrass | 39 | 319117.644 | 3032936.311 | 3 |
| 427 | Seagrass | 39 | 318964.505 | 3034124.431 | 3 |
| 428 | Seagrass | 39 | 327638.595 | 3034808.828 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 429 | Seagrass | 39 | 331051.152 | 3029645.042 | 3 |
| 430 | Seagrass | 39 | 319257.449 | 3034777.733 | 3 |
| 431 | Seagrass | 39 | 329469.353 | 3028304.081 | 3 |
| 432 | Seagrass | 39 | 321141.621 | 3033719.897 | 3 |
| 433 | Seagrass | 39 | 335530.384 | 3032613.525 | 3 |
| 434 | Seagrass | 39 | 326767.122 | 3033181.800 | 3 |
| 435 | Seagrass | 39 | 337340.936 | 3036176.575 | 3 |
| 436 | Seagrass | 39 | 334960.576 | 3036945.111 | 3 |
| 437 | Seagrass | 39 | 336682.886 | 3037102.648 | 3 |
| 438 | Seagrass | 39 | 335880.629 | 3036847.651 | 3 |
| 439 | Seagrass | 39 | 332216.348 | 3037045.508 | 3 |
| 440 | Seagrass | 39 | 334233.194 | 3037693.821 | 3 |
| 441 | Seagrass | 39 | 335108.220 | 3038268.783 | 3 |
| 442 | Seagrass | 39 | 335497.268 | 3038428.244 | 3 |
| 443 | Seagrass | 39 | 333227.360 | 3039260.614 | 3 |
| 444 | Seagrass | 39 | 333723.210 | 3038957.813 | 3 |
| 445 | Seagrass | 39 | 331309.182 | 3041608.866 | 3 |
| 446 | Seagrass | 39 | 331483.113 | 3042743.965 | 3 |
| 447 | Seagrass | 39 | 331246.219 | 3043312.140 | 3 |
| 448 | Seagrass | 39 | 329402.355 | 3044419.011 | 3 |
| 449 | Seagrass | 39 | 329382.645 | 3044026.650 | 3 |
| 450 | Seagrass | 39 | 328860.229 | 3044723.874 | 3 |
| 451 | Seagrass | 39 | 330357.871 | 3044710.073 | 3 |
| 452 | Seagrass | 39 | 331235.206 | 3043967.950 | 3 |
| 453 | Seagrass | 39 | 329253.236 | 3046248.128 | 3 |
| 454 | Seagrass | 39 | 327717.572 | 3046621.999 | 3 |
| 455 | Seagrass | 39 | 327152.689 | 3046993.907 | 3 |
| 456 | Seagrass | 39 | 328459.983 | 3046916.582 | 3 |
| 457 | Seagrass | 39 | 326581.883 | 3046984.635 | 3 |
| 458 | Seagrass | 39 | 325587.235 | 3047412.657 | 3 |
| 459 | Seagrass | 39 | 325295.054 | 3047379.624 | 3 |
| 460 | Seagrass | 39 | 325800.147 | 3047975.783 | 3 |
| 461 | Seagrass | 39 | 324969.267 | 3047872.122 | 3 |
| 462 | Seagrass | 39 | 327346.132 | 3047703.635 | 3 |
| 463 | Seagrass | 39 | 311601.865 | 3049352.470 | 3 |
| 464 | Seagrass | 39 | 327551.194 | 3048852.005 | 3 |
| 465 | Seagrass | 39 | 325601.510 | 3048869.108 | 3 |
| 466 | Seagrass | 39 | 311345.246 | 3049773.933 | 3 |
| 467 | Seagrass | 39 | 323150.831 | 3049148.860 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 468 | Seagrass | 39 | 326615.228 | 3049704.820 | 3 |
| 469 | Seagrass | 39 | 323567.455 | 3050070.016 | 3 |
| 470 | Seagrass | 39 | 293062.837 | 3051401.935 | 3 |
| 471 | Seagrass | 39 | 293568.502 | 3051815.042 | 3 |
| 472 | Seagrass | 39 | 326071.068 | 3050269.572 | 3 |
| 473 | Seagrass | 39 | 325022.603 | 3050825.691 | 3 |
| 474 | Seagrass | 39 | 294406.239 | 3052774.046 | 3 |
| 475 | Seagrass | 39 | 294028.761 | 3052835.897 | 3 |
| 476 | Seagrass | 39 | 320155.527 | 3052118.918 | 3 |
| 477 | Seagrass | 39 | 294821.955 | 3053400.048 | 3 |
| 478 | Seagrass | 39 | 320570.543 | 3052430.989 | 3 |
| 479 | Seagrass | 39 | 320323.977 | 3052639.567 | 3 |
| 480 | Seagrass | 39 | 320613.535 | 3052830.697 | 3 |
| 481 | Seagrass | 39 | 320509.185 | 3053073.397 | 3 |
| 482 | Seagrass | 39 | 290380.339 | 3054442.605 | 3 |
| 483 | Seagrass | 39 | 287752.441 | 3055522.895 | 3 |
| 484 | Seagrass | 39 | 287603.866 | 3056264.664 | 3 |
| 485 | Seagrass | 39 | 287239.092 | 3056724.723 | 3 |
| 486 | Seagrass | 39 | 293024.146 | 3054084.552 | 3 |
| 487 | Seagrass | 39 | 302719.289 | 3056045.389 | 3 |
| 488 | Seagrass | 39 | 301883.403 | 3056603.307 | 3 |
| 489 | Seagrass | 39 | 301562.781 | 3056634.829 | 3 |
| 490 | Seagrass | 39 | 288931.599 | 3057014.919 | 3 |
| 491 | Seagrass | 39 | 303344.221 | 3056601.242 | 3 |
| 492 | Seagrass | 39 | 301922.260 | 3056838.533 | 3 |
| 493 | Seagrass | 39 | 301815.925 | 3056977.843 | 3 |
| 494 | Seagrass | 39 | 300955.539 | 3056883.275 | 3 |
| 495 | Seagrass | 39 | 300237.483 | 3057310.069 | 3 |
| 496 | Seagrass | 39 | 300691.873 | 3058094.467 | 3 |
| 497 | Seagrass | 39 | 301147.631 | 3058254.002 | 3 |
| 498 | Seagrass | 39 | 300671.700 | 3058312.502 | 3 |
| 499 | Seagrass | 39 | 290782.725 | 3056570.912 | 3 |
| 500 | Seagrass | 39 | 291135.682 | 3055808.007 | 3 |
| 501 | Seagrass | 39 | 290059.804 | 3058434.164 | 3 |
| 502 | Seagrass | 39 | 300971.738 | 3058458.603 | 3 |
| 503 | Seagrass | 39 | 300810.587 | 3058494.656 | 3 |
| 504 | Seagrass | 39 | 300253.754 | 3058986.771 | 3 |
| 505 | Seagrass | 39 | 301598.620 | 3059054.886 | 3 |
| 506 | Seagrass | 39 | 300757.435 | 3059783.927 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 507 | Seagrass | 39 | 295389.822 | 3059971.739 | 3 |
| 508 | Seagrass | 39 | 295814.484 | 3060096.980 | 3 |
| 509 | Seagrass | 39 | 295802.477 | 3061468.522 | 3 |
| 510 | Seagrass | 39 | 299626.442 | 3060605.357 | 3 |
| 511 | Seagrass | 39 | 299313.640 | 3061287.638 | 3 |
| 512 | Seagrass | 39 | 294674.029 | 3061153.442 | 3 |
| 513 | Seagrass | 39 | 295121.368 | 3061839.776 | 3 |
| 514 | Seagrass | 39 | 291408.262 | 3063475.123 | 3 |
| 515 | Seagrass | 39 | 293564.305 | 3063885.331 | 3 |
| 516 | Seagrass | 39 | 292321.713 | 3064472.921 | 3 |
| 517 | Seagrass | 39 | 295762.469 | 3064229.499 | 3 |
| 518 | Seagrass | 39 | 295736.774 | 3063678.498 | 3 |
| 519 | Seagrass | 39 | 294580.401 | 3064461.394 | 3 |
| 520 | Seagrass | 39 | 293392.674 | 3065821.263 | 3 |
| 521 | Seagrass | 39 | 291632.535 | 3060251.901 | 3 |
| 522 | Seagrass | 39 | 291480.629 | 3065134.446 | 3 |
| 523 | Seagrass | 39 | 293972.299 | 3067641.967 | 3 |
| 524 | Seagrass | 39 | 292977.417 | 3060843.769 | 3 |
| 525 | Seagrass | 39 | 292193.100 | 3065764.192 | 3 |
| 526 | Seagrass | 39 | 288430.195 | 3063075.253 | 3 |
| 527 | Seagrass | 39 | 292750.085 | 3065631.399 | 3 |
| 528 | Seagrass | 39 | 290106.735 | 3062113.956 | 3 |
| 529 | Seagrass | 39 | 291086.472 | 3064358.790 | 3 |
| 530 | Seagrass | 39 | 293179.061 | 3061430.275 | 3 |
| 531 | Seagrass | 39 | 295041.073 | 3068298.189 | 3 |
| 532 | Seagrass | 39 | 295162.323 | 3067738.355 | 3 |
| 533 | Seagrass | 39 | 293643.470 | 3069029.127 | 3 |
| 534 | Seagrass | 39 | 290789.568 | 3068698.644 | 3 |
| 535 | Seagrass | 39 | 293096.459 | 3069838.251 | 3 |
| 536 | Seagrass | 39 | 292711.794 | 3069750.606 | 3 |
| 537 | Seagrass | 39 | 292640.663 | 3071118.667 | 3 |
| 538 | Seagrass | 39 | 291665.815 | 3071362.443 | 3 |
| 539 | Seagrass | 39 | 293008.025 | 3070536.939 | 3 |
| 540 | Seagrass | 39 | 292712.673 | 3071807.222 | 3 |
| 541 | Seagrass | 39 | 291884.973 | 3071638.452 | 3 |
| 542 | Seagrass | 39 | 291969.513 | 3072076.422 | 3 |
| 543 | Seagrass | 39 | 293015.207 | 3072292.532 | 3 |
| 544 | Seagrass | 39 | 292366.206 | 3072408.973 | 3 |
| 545 | Seagrass | 39 | 293494.379 | 3072818.670 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 546 | Seagrass | 39 | 293703.183 | 3073357.926 | 3 |
| 547 | Seagrass | 39 | 285942.970 | 3070557.598 | 3 |
| 548 | Seagrass | 39 | 286833.609 | 3072093.197 | 3 |
| 549 | Seagrass | 39 | 285036.530 | 3071024.429 | 3 |
| 550 | Seagrass | 39 | 287686.850 | 3066980.446 | 3 |
| 551 | Seagrass | 39 | 287464.786 | 3071678.512 | 3 |
| 552 | Seagrass | 39 | 285720.625 | 3066455.427 | 3 |
| 553 | Seagrass | 39 | 286953.467 | 3070756.533 | 3 |
| 554 | Seagrass | 39 | 283727.730 | 3069174.775 | 3 |
| 555 | Seagrass | 39 | 285711.317 | 3064967.211 | 3 |
| 556 | Seagrass | 39 | 286417.410 | 3066765.861 | 3 |
| 557 | Seagrass | 39 | 286576.562 | 3065237.075 | 3 |
| 558 | Seagrass | 39 | 282767.961 | 3067537.357 | 3 |
| 559 | Seagrass | 39 | 283421.109 | 3071790.246 | 3 |
| 560 | Seagrass | 39 | 283138.920 | 3068160.692 | 3 |
| 561 | Seagrass | 39 | 286569.742 | 3068930.630 | 3 |
| 562 | Seagrass | 39 | 283888.058 | 3071175.827 | 3 |
| 563 | Seagrass | 39 | 289531.500 | 3069041.420 | 3 |
| 564 | Seagrass | 39 | 282048.582 | 3067108.622 | 3 |
| 565 | Seagrass | 39 | 287927.251 | 3066470.660 | 3 |
| 566 | Seagrass | 39 | 294207.201 | 3074123.517 | 3 |
| 567 | Seagrass | 39 | 293075.328 | 3074574.723 | 3 |
| 568 | Seagrass | 39 | 294254.101 | 3074726.524 | 3 |
| 569 | Seagrass | 39 | 289637.995 | 3075390.033 | 3 |
| 570 | Seagrass | 39 | 294328.762 | 3075025.514 | 3 |
| 571 | Seagrass | 39 | 288698.115 | 3075447.630 | 3 |
| 572 | Seagrass | 39 | 293336.482 | 3076428.009 | 3 |
| 573 | Seagrass | 39 | 293871.272 | 3075626.876 | 3 |
| 574 | Seagrass | 39 | 293934.038 | 3076533.851 | 3 |
| 575 | Seagrass | 39 | 284787.161 | 3076898.042 | 3 |
| 576 | Seagrass | 39 | 285169.257 | 3076808.776 | 3 |
| 577 | Seagrass | 39 | 285613.011 | 3076329.764 | 3 |
| 578 | Seagrass | 39 | 285010.932 | 3077222.061 | 3 |
| 579 | Seagrass | 39 | 292006.853 | 3076934.969 | 3 |
| 580 | Seagrass | 39 | 291415.786 | 3077181.963 | 3 |
| 581 | Seagrass | 39 | 292103.553 | 3077616.954 | 3 |
| 582 | Seagrass | 39 | 291723.320 | 3077391.464 | 3 |
| 583 | Seagrass | 39 | 284460.936 | 3077840.745 | 3 |
| 584 | Seagrass | 39 | 287404.464 | 3074689.979 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 585 | Seagrass | 39 | 288074.956 | 3078221.764 | 3 |
| 586 | Seagrass | 39 | 287184.657 | 3076848.645 | 3 |
| 587 | Seagrass | 39 | 291748.486 | 3079512.789 | 3 |
| 588 | Seagrass | 39 | 292957.285 | 3079186.083 | 3 |
| 589 | Seagrass | 39 | 283559.631 | 3092272.283 | 3 |
| 590 | Seagrass | 39 | 284609.182 | 3091515.585 | 3 |
| 591 | Seagrass | 39 | 284285.242 | 3090190.697 | 3 |
| 592 | Seagrass | 39 | 285144.727 | 3091084.415 | 3 |
| 593 | Seagrass | 39 | 282042.574 | 3093067.510 | 3 |
| 594 | Seagrass | 39 | 280023.577 | 3094527.462 | 3 |
| 595 | Seagrass | 39 | 282970.132 | 3093155.822 | 3 |
| 596 | Seagrass | 39 | 278327.471 | 3095361.180 | 3 |
| 597 | Seagrass | 39 | 284337.524 | 3096987.050 | 3 |
| 598 | Seagrass | 39 | 282283.206 | 3097151.135 | 3 |
| 599 | Seagrass | 39 | 276559.917 | 3100594.672 | 3 |
| 600 | Seagrass | 39 | 276399.720 | 3100726.678 | 3 |
| 601 | Seagrass | 39 | 288684.316 | 3100720.487 | 3 |
| 602 | Seagrass | 39 | 289651.197 | 3100728.679 | 3 |
| 603 | Seagrass | 39 | 273497.541 | 3102156.133 | 3 |
| 604 | Seagrass | 39 | 290705.469 | 3101424.396 | 3 |
| 605 | Seagrass | 39 | 273437.304 | 3102411.265 | 3 |
| 606 | Seagrass | 39 | 290558.017 | 3101569.863 | 3 |
| 607 | Seagrass | 39 | 270623.150 | 3104273.080 | 3 |
| 608 | Seagrass | 39 | 292444.561 | 3103740.199 | 3 |
| 609 | Seagrass | 39 | 277676.694 | 3105035.008 | 3 |
| 610 | Seagrass | 39 | 277104.983 | 3105269.411 | 3 |
| 611 | Seagrass | 39 | 269871.960 | 3105625.913 | 3 |
| 612 | Seagrass | 39 | 281314.222 | 3103275.123 | 3 |
| 613 | Seagrass | 39 | 273013.002 | 3104097.739 | 3 |
| 614 | Seagrass | 39 | 280259.313 | 3103613.479 | 3 |
| 615 | Seagrass | 39 | 275879.138 | 3101089.798 | 3 |
| 616 | Seagrass | 39 | 274868.025 | 3103627.963 | 3 |
| 617 | Seagrass | 39 | 273240.288 | 3104952.863 | 3 |
| 618 | Seagrass | 39 | 278843.242 | 3103121.223 | 3 |
| 619 | Seagrass | 39 | 271200.420 | 3103482.330 | 3 |
| 620 | Seagrass | 39 | 271912.344 | 3104383.721 | 3 |
| 621 | Seagrass | 39 | 274092.499 | 3100967.560 | 3 |
| 622 | Seagrass | 39 | 275378.173 | 3102274.325 | 3 |
| 623 | Seagrass | 39 | 274375.448 | 3101672.857 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 624 | Seagrass | 39 | 274724.532 | 3102839.029 | 3 |
| 625 | Seagrass | 39 | 272474.238 | 3105251.915 | 3 |
| 626 | Seagrass | 39 | 277489.393 | 3105489.220 | 3 |
| 627 | Seagrass | 39 | 289788.982 | 3102990.736 | 3 |
| 628 | Seagrass | 39 | 290476.097 | 3091280.527 | 3 |
| 629 | Seagrass | 39 | 292327.712 | 3082948.397 | 3 |
| 630 | Seagrass | 39 | 289175.017 | 3103645.031 | 3 |
| 631 | Seagrass | 39 | 287275.152 | 3089359.559 | 3 |
| 632 | Seagrass | 39 | 291669.017 | 3101406.314 | 3 |
| 633 | Seagrass | 39 | 289911.884 | 3090595.354 | 3 |
| 634 | Seagrass | 39 | 293108.536 | 3080224.804 | 3 |
| 635 | Seagrass | 39 | 289213.401 | 3100519.768 | 3 |
| 636 | Seagrass | 39 | 290480.517 | 3100634.839 | 3 |
| 637 | Seagrass | 39 | 285581.668 | 3100576.067 | 3 |
| 638 | Seagrass | 39 | 291716.953 | 3082861.867 | 3 |
| 639 | Seagrass | 39 | 292892.159 | 3081522.251 | 3 |
| 640 | Seagrass | 39 | 289895.504 | 3100244.208 | 3 |
| 641 | Seagrass | 39 | 278342.720 | 3100037.640 | 3 |
| 642 | Seagrass | 39 | 286834.325 | 3100470.681 | 3 |
| 643 | Seagrass | 39 | 279172.366 | 3100274.372 | 3 |
| 644 | Seagrass | 39 | 290733.670 | 3095279.887 | 3 |
| 645 | Seagrass | 39 | 288725.770 | 3103035.325 | 3 |
| 646 | Seagrass | 39 | 290002.171 | 3097036.658 | 3 |
| 647 | Seagrass | 39 | 291515.095 | 3085299.140 | 3 |
| 648 | Seagrass | 39 | 285682.025 | 3095608.803 | 3 |
| 649 | Seagrass | 39 | 287559.253 | 3103075.370 | 3 |
| 650 | Seagrass | 39 | 289680.167 | 3093366.368 | 3 |
| 651 | Seagrass | 39 | 286265.743 | 3096500.063 | 3 |
| 652 | Seagrass | 39 | 287342.783 | 3104813.547 | 3 |
| 653 | Seagrass | 39 | 287886.983 | 3104183.562 | 3 |
| 654 | Seagrass | 39 | 285316.111 | 3101930.204 | 3 |
| 655 | Seagrass | 39 | 284124.884 | 3099464.021 | 3 |
| 656 | Seagrass | 39 | 287605.733 | 3099436.738 | 3 |
| 657 | Seagrass | 39 | 289941.707 | 3092037.274 | 3 |
| 658 | Seagrass | 39 | 291107.093 | 3081744.172 | 3 |
| 659 | Seagrass | 39 | 289658.327 | 3096297.621 | 3 |
| 660 | Seagrass | 39 | 286508.701 | 3103116.001 | 3 |
| 661 | Seagrass | 39 | 286754.027 | 3087491.152 | 3 |
| 662 | Seagrass | 39 | 288779.208 | 3093545.130 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 663 | Seagrass | 39 | 282703.546 | 3099965.937 | 3 |
| 664 | Seagrass | 39 | 289210.579 | 3096867.529 | 3 |
| 665 | Seagrass | 39 | 290588.707 | 3090039.393 | 3 |
| 666 | Seagrass | 39 | 288928.208 | 3101370.037 | 3 |
| 667 | Seagrass | 39 | 291439.156 | 3083345.388 | 3 |
| 668 | Seagrass | 39 | 289317.205 | 3095113.777 | 3 |
| 669 | Seagrass | 39 | 291332.612 | 3090543.009 | 3 |
| 670 | Seagrass | 39 | 279747.476 | 3099833.601 | 3 |
| 671 | Seagrass | 39 | 289048.634 | 3096110.602 | 3 |
| 672 | Seagrass | 39 | 281346.148 | 3099708.902 | 3 |
| 673 | Seagrass | 39 | 286502.260 | 3088060.900 | 3 |
| 674 | Seagrass | 39 | 290320.481 | 3096131.879 | 3 |
| 675 | Seagrass | 39 | 286316.712 | 3101206.180 | 3 |
| 676 | Seagrass | 39 | 289811.877 | 3098735.846 | 3 |
| 677 | Seagrass | 39 | 291669.877 | 3102398.687 | 3 |
| 678 | Seagrass | 39 | 286770.486 | 3099895.059 | 3 |
| 679 | Seagrass | 39 | 291999.254 | 3091227.434 | 3 |
| 680 | Seagrass | 39 | 289804.259 | 3098067.394 | 3 |
| 681 | Seagrass | 39 | 287982.445 | 3095709.026 | 3 |
| 682 | Seagrass | 39 | 277126.073 | 3100466.109 | 3 |
| 683 | Seagrass | 39 | 290770.041 | 3102966.562 | 3 |
| 684 | Seagrass | 39 | 293385.485 | 3101495.096 | 3 |
| 685 | Seagrass | 39 | 290525.438 | 3088188.575 | 3 |
| 686 | Seagrass | 39 | 289629.467 | 3094447.588 | 3 |
| 687 | Seagrass | 39 | 288490.237 | 3091123.700 | 3 |
| 688 | Seagrass | 39 | 290298.865 | 3085260.587 | 3 |
| 689 | Seagrass | 39 | 291952.268 | 3081513.353 | 3 |
| 690 | Seagrass | 39 | 288317.335 | 3103761.014 | 3 |
| 691 | Seagrass | 39 | 289577.544 | 3088470.309 | 3 |
| 692 | Seagrass | 39 | 288151.793 | 3088213.234 | 3 |
| 693 | Seagrass | 39 | 290114.122 | 3099433.982 | 3 |
| 694 | Seagrass | 39 | 285710.913 | 3103324.165 | 3 |
| 695 | Seagrass | 39 | 287125.465 | 3085535.974 | 3 |
| 696 | Seagrass | 39 | 293133.408 | 3100091.036 | 3 |
| 697 | Seagrass | 39 | 293863.848 | 3082680.437 | 3 |
| 698 | Seagrass | 39 | 289190.104 | 3084819.902 | 3 |
| 699 | Seagrass | 39 | 291388.918 | 3089877.440 | 3 |
| 700 | Seagrass | 39 | 289342.187 | 3086220.593 | 3 |
| 701 | Seagrass | 39 | 289423.946 | 3090122.864 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 702 | Seagrass | 39 | 288291.698 | 3087635.298 | 3 |
| 703 | Seagrass | 39 | 280394.266 | 3101205.066 | 3 |
| 704 | Seagrass | 39 | 290502.119 | 3097257.993 | 3 |
| 705 | Seagrass | 39 | 295005.836 | 3081625.654 | 3 |
| 706 | Seagrass | 39 | 291237.224 | 3097758.059 | 3 |
| 707 | Seagrass | 39 | 279045.223 | 3100942.469 | 3 |
| 708 | Seagrass | 39 | 287952.517 | 3100530.400 | 3 |
| 709 | Seagrass | 39 | 287309.432 | 3105564.611 | 3 |
| 710 | Seagrass | 39 | 290161.497 | 3093666.913 | 3 |
| 711 | Seagrass | 39 | 291163.946 | 3087808.090 | 3 |
| 712 | Seagrass | 39 | 291167.791 | 3084178.017 | 3 |
| 713 | Seagrass | 39 | 288637.727 | 3084837.660 | 3 |
| 714 | Seagrass | 39 | 288019.231 | 3093933.241 | 3 |
| 715 | Seagrass | 39 | 287607.926 | 3092888.861 | 3 |
| 716 | Seagrass | 39 | 289967.119 | 3102215.235 | 3 |
| 717 | Seagrass | 39 | 286720.609 | 3095385.722 | 3 |
| 718 | Seagrass | 39 | 294020.075 | 3100778.708 | 3 |
| 719 | Seagrass | 39 | 290436.365 | 3098876.357 | 3 |
| 720 | Seagrass | 39 | 287703.295 | 3086259.228 | 3 |
| 721 | Seagrass | 39 | 291379.471 | 3086354.465 | 3 |
| 722 | Seagrass | 39 | 290871.179 | 3096049.616 | 3 |
| 723 | Seagrass | 39 | 293754.094 | 3080706.080 | 3 |
| 724 | Seagrass | 39 | 278205.612 | 3105918.929 | 3 |
| 725 | Seagrass | 39 | 269424.831 | 3106342.712 | 3 |
| 726 | Seagrass | 39 | 269049.828 | 3106655.966 | 3 |
| 727 | Seagrass | 39 | 268745.627 | 3106993.189 | 3 |
| 728 | Seagrass | 39 | 276827.099 | 3106553.780 | 3 |
| 729 | Seagrass | 39 | 277465.124 | 3106019.432 | 3 |
| 730 | Seagrass | 39 | 269307.596 | 3107113.184 | 3 |
| 731 | Seagrass | 39 | 268387.235 | 3107697.578 | 3 |
| 732 | Seagrass | 39 | 267795.539 | 3108494.214 | 3 |
| 733 | Seagrass | 39 | 292827.041 | 3107715.500 | 3 |
| 734 | Seagrass | 39 | 267317.606 | 3108971.972 | 3 |
| 735 | Seagrass | 39 | 293912.935 | 3107994.399 | 3 |
| 736 | Seagrass | 39 | 294332.958 | 3107872.702 | 3 |
| 737 | Seagrass | 39 | 292967.929 | 3107812.232 | 3 |
| 738 | Seagrass | 39 | 294830.745 | 3108206.242 | 3 |
| 739 | Seagrass | 39 | 293866.594 | 3108310.945 | 3 |
| 740 | Seagrass | 39 | 266831.600 | 3109502.768 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 741 | Seagrass | 39 | 294873.310 | 3108580.816 | 3 |
| 742 | Seagrass | 39 | 266582.869 | 3109926.399 | 3 |
| 743 | Seagrass | 39 | 293206.794 | 3109132.997 | 3 |
| 744 | Seagrass | 39 | 266108.726 | 3110874.322 | 3 |
| 745 | Seagrass | 39 | 266540.915 | 3111009.189 | 3 |
| 746 | Seagrass | 39 | 267575.014 | 3111197.394 | 3 |
| 747 | Seagrass | 39 | 267634.690 | 3111582.624 | 3 |
| 748 | Seagrass | 39 | 289525.996 | 3109012.530 | 3 |
| 749 | Seagrass | 39 | 290522.566 | 3107269.769 | 3 |
| 750 | Seagrass | 39 | 292057.981 | 3107682.537 | 3 |
| 751 | Seagrass | 39 | 289422.723 | 3109726.153 | 3 |
| 752 | Seagrass | 39 | 291100.719 | 3106805.963 | 3 |
| 753 | Seagrass | 39 | 291913.937 | 3108235.284 | 3 |
| 754 | Seagrass | 39 | 291866.005 | 3105469.511 | 3 |
| 755 | Seagrass | 39 | 268390.645 | 3111527.875 | 3 |
| 756 | Seagrass | 39 | 271275.601 | 3112226.518 | 3 |
| 757 | Seagrass | 39 | 270911.152 | 3112522.235 | 3 |
| 758 | Seagrass | 39 | 272522.758 | 3112905.951 | 3 |
| 759 | Seagrass | 39 | 270033.266 | 3115802.769 | 3 |
| 760 | Seagrass | 39 | 271178.110 | 3122293.310 | 3 |
| 761 | Seagrass | 39 | 271560.204 | 3122463.885 | 3 |
| 762 | Seagrass | 39 | 271377.324 | 3122844.471 | 3 |
| 763 | Seagrass | 39 | 271587.957 | 3123403.947 | 3 |
| 764 | Seagrass | 39 | 271981.483 | 3118891.839 | 3 |
| 765 | Seagrass | 39 | 269551.739 | 3119326.736 | 3 |
| 766 | Seagrass | 39 | 266485.028 | 3111719.521 | 3 |
| 767 | Seagrass | 39 | 266844.895 | 3119139.677 | 3 |
| 768 | Seagrass | 39 | 266651.491 | 3112356.172 | 3 |
| 769 | Seagrass | 39 | 266925.157 | 3112937.306 | 3 |
| 770 | Seagrass | 39 | 267141.532 | 3112194.718 | 3 |
| 771 | Seagrass | 39 | 272617.686 | 3118288.605 | 3 |
| 772 | Seagrass | 39 | 268659.503 | 3122939.080 | 3 |
| 773 | Seagrass | 39 | 267390.852 | 3116380.585 | 3 |
| 774 | Seagrass | 39 | 267920.025 | 3115427.870 | 3 |
| 775 | Seagrass | 39 | 266573.467 | 3120237.694 | 3 |
| 776 | Seagrass | 39 | 267752.974 | 3117097.022 | 3 |
| 777 | Seagrass | 39 | 268312.100 | 3118480.301 | 3 |
| 778 | Seagrass | 39 | 270427.259 | 3119116.421 | 3 |
| 779 | Seagrass | 39 | 269443.468 | 3123985.469 | 3 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 780 | Seagrass | 39 | 268854.724 | 3115510.440 | 3 |
| 781 | Seagrass | 39 | 266672.996 | 3116437.115 | 3 |
| 782 | Seagrass | 39 | 266102.887 | 3118042.480 | 3 |
| 783 | Seagrass | 39 | 268734.082 | 3120586.540 | 3 |
| 784 | Seagrass | 39 | 269481.146 | 3117987.021 | 3 |
| 785 | Seagrass | 39 | 268356.522 | 3122039.860 | 3 |
| 786 | Seagrass | 39 | 270076.494 | 3119916.232 | 3 |
| 787 | Seagrass | 39 | 269008.421 | 3121034.236 | 3 |
| 788 | Seagrass | 39 | 267214.434 | 3115712.185 | 3 |
| 789 | Seagrass | 39 | 263069.593 | 3128195.380 | 3 |
| 790 | Seagrass | 39 | 261629.407 | 3128786.421 | 3 |
| 791 | Seagrass | 39 | 260852.717 | 3129223.905 | 3 |
| 792 | Seagrass | 39 | 259007.687 | 3131214.895 | 3 |
| 793 | Seagrass | 39 | 258659.742 | 3131420.093 | 3 |
| 794 | Seagrass | 39 | 258527.908 | 3132063.072 | 3 |
| 795 | Seagrass | 39 | 259164.885 | 3131593.523 | 3 |
| 796 | Seagrass | 39 | 258247.787 | 3133016.344 | 3 |
| 797 | Seagrass | 39 | 257586.098 | 3141055.498 | 3 |
| 798 | Seagrass | 39 | 257993.453 | 3138481.214 | 3 |
| 799 | Seagrass | 39 | 261262.222 | 3132488.553 | 3 |
| 800 | Seagrass | 39 | 260788.924 | 3130906.534 | 3 |
| 801 | Seagrass | 39 | 259014.935 | 3136073.718 | 3 |
| 802 | Seagrass | 39 | 258642.122 | 3133724.589 | 3 |
| 803 | Seagrass | 39 | 257862.125 | 3135549.787 | 3 |
| 804 | Seagrass | 39 | 258328.930 | 3136116.873 | 3 |
| 805 | Seagrass | 39 | 257860.140 | 3140387.383 | 3 |
| 806 | Seagrass | 39 | 258205.189 | 3134805.120 | 3 |
| 807 | Seagrass | 39 | 259958.465 | 3130324.866 | 3 |
| 808 | Seagrass | 39 | 257517.910 | 3136113.518 | 3 |
| 809 | Seagrass | 39 | 261191.094 | 3133108.773 | 3 |
| 810 | Seagrass | 39 | 261234.510 | 3131986.610 | 3 |
| 811 | Seagrass | 39 | 259122.769 | 3135166.009 | 3 |
| 812 | Seagrass | 39 | 258244.124 | 3141507.164 | 3 |
| 813 | Seagrass | 39 | 257877.591 | 3141469.743 | 3 |
| 814 | Seagrass | 39 | 258325.154 | 3141858.503 | 3 |
| 815 | Seagrass | 39 | 258822.014 | 3142401.245 | 3 |
| 816 | Seagrass | 39 | 422976.654 | 2922932.882 | 3 |
| 817 | Mangrove | 39 | 349691.186 | 3002110.705 | 5 |
| 818 | Mangrove | 39 | 405747.230 | 2941841.476 | 5 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 819 | Mangrove | 39 | 401171.369 | 2958113.283 | 5 |
| 820 | Mangrove | 39 | 405747.230 | 2941841.476 | 5 |
| 821 | Mangrove | 39 | 402735.346 | 2954913.425 | 5 |
| 822 | Mangrove | 39 | 365086.416 | 3022086.560 | 5 |
| 823 | Mangrove | 39 | 358290.037 | 3018912.571 | 5 |
| 824 | Mangrove | 39 | 300461.293 | 3056568.766 | 5 |
| 825 | Mangrove | 39 | 419089.513 | 2928163.197 | 5 |
| 826 | Mangrove | 39 | 416351.179 | 2923018.422 | 5 |
| 827 | Mangrove | 39 | 404626.463 | 2932130.253 | 5 |
| 828 | Mangrove | 39 | 405987.736 | 2941632.005 | 5 |
| 829 | Mangrove | 39 | 402040.735 | 2948773.710 | 5 |
| 830 | Mangrove | 39 | 401281.434 | 2956387.425 | 5 |
| 831 | Mangrove | 39 | 410837.693 | 2951140.599 | 5 |
| 832 | Mangrove | 39 | 400073.862 | 2957296.115 | 5 |
| 833 | Mangrove | 39 | 400647.307 | 2949290.323 | 5 |
| 834 | Mangrove | 39 | 401868.846 | 2947468.058 | 5 |
| 835 | Salt Marshes | 39 | 400575.642 | 2959018.752 | 4 |
| 836 | Salt Marshes | 39 | 403536.135 | 2952696.414 | 4 |
| 837 | Salt Marshes | 39 | 401174.471 | 2949012.037 | 4 |
| 838 | Salt Marshes | 39 | 399987.224 | 2949029.212 | 4 |
| 839 | Salt Marshes | 39 | 406563.844 | 2942096.600 | 4 |
| 840 | Salt Marshes | 39 | 358483.809 | 3006482.877 | 4 |
| 841 | Salt Marshes | 39 | 359765.169 | 3006129.060 | 4 |
| 842 | Salt Marshes | 39 | 362735.262 | 3021669.872 | 4 |
| 843 | Salt Marshes | 39 | 360302.527 | 3020460.518 | 4 |
| 844 | Salt Marshes | 39 | 354990.130 | 3020569.682 | 4 |
| 845 | Salt Marshes | 39 | 358358.550 | 3019844.845 | 4 |
| 846 | Salt Marshes | 39 | 336104.824 | 3011647.787 | 4 |
| 847 | Salt Marshes | 39 | 336304.804 | 3009932.396 | 4 |
| 848 | Salt Marshes | 39 | 324463.996 | 3031705.260 | 4 |
| 849 | Salt Marshes | 39 | 323762.791 | 3032606.079 | 4 |
| 850 | Salt Marshes | 39 | 328341.566 | 3036250.948 | 4 |
| 851 | Salt Marshes | 39 | 323015.770 | 3036534.166 | 4 |
| 852 | Salt Marshes | 39 | 320883.327 | 3037116.628 | 4 |
| 853 | Salt Marshes | 39 | 318459.342 | 3035414.474 | 4 |
| 854 | Salt Marshes | 39 | 319456.085 | 3032271.117 | 4 |
| 855 | Salt Marshes | 39 | 320853.254 | 3031230.187 | 4 |
| 856 | Salt Marshes | 39 | 323995.203 | 3029294.212 | 4 |
| 857 | Salt Marshes | 39 | 340580.495 | 3010088.974 | 4 |

| Object ID | Habitat Class | Coordinates UTM 1984 | | | ESI Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| 858 | Salt Marshes | 39 | 332146.589 | 3038674.027 | 4 |
| 859 | Salt Marshes | 39 | 329986.039 | 3035832.908 | 4 |
| 860 | Salt Marshes | 39 | 317505.283 | 3035928.581 | 4 |
| 861 | Salt Marshes | 39 | 315921.640 | 3033477.638 | 4 |
| 862 | Salt Marshes | 39 | 325438.146 | 3036432.529 | 4 |
| 863 | Salt Marshes | 39 | 327517.758 | 3028687.974 | 4 |
| 864 | Salt Marshes | 39 | 324899.888 | 3027389.309 | 4 |
| 865 | Salt Marshes | 39 | 325845.560 | 3026661.739 | 4 |
| 866 | Salt Marshes | 39 | 327958.417 | 3024017.746 | 4 |
| 867 | Salt Marshes | 39 | 334335.431 | 3015140.848 | 4 |
| 868 | Salt Marshes | 39 | 333748.124 | 3011793.469 | 4 |
| 869 | Salt Marshes | 39 | 335113.750 | 3013803.132 | 4 |
| 870 | Salt Marshes | 39 | 338477.742 | 3009633.445 | 4 |
| 871 | Salt Marshes | 39 | 336010.958 | 3008185.184 | 4 |
| 872 | Salt Marshes | 39 | 337298.260 | 3005822.251 | 4 |
| 873 | Salt Marshes | 39 | 341893.485 | 3005445.725 | 4 |
| 874 | Salt Marshes | 39 | 338808.092 | 3003734.604 | 4 |
| 875 | Salt Marshes | 39 | 339465.676 | 3002789.311 | 4 |
| 876 | Salt Marshes | 39 | 348209.281 | 3000977.719 | 4 |
| 877 | Salt Marshes | 39 | 347829.853 | 3016956.100 | 4 |
| 878 | Salt Marshes | 39 | 349964.991 | 3016690.850 | 4 |
| 879 | Salt Marshes | 39 | 352109.140 | 3014120.105 | 4 |
| 880 | Salt Marshes | 39 | 350604.927 | 3021272.574 | 4 |
| 881 | Salt Marshes | 39 | 350980.643 | 3019032.769 | 4 |
| 882 | Salt Marshes | 39 | 284383.640 | 3068992.402 | 4 |
| 883 | Salt Marshes | 39 | 284295.814 | 3070751.943 | 4 |
| 884 | Salt Marshes | 39 | 286075.025 | 3063352.134 | 4 |
| 885 | Salt Marshes | 39 | 287692.656 | 3065955.266 | 4 |
| 886 | Salt Marshes | 39 | 285253.693 | 3072687.550 | 4 |
| 887 | Salt Marshes | 39 | 286734.782 | 3073150.363 | 4 |
| 888 | Salt Marshes | 39 | 288556.242 | 3064263.199 | 4 |
| 889 | Salt Marshes | 39 | 288096.105 | 3062328.849 | 4 |
| 890 | Salt Marshes | 39 | 289611.910 | 3061225.747 | 4 |
| 891 | Salt Marshes | 39 | 287834.248 | 3059817.728 | 4 |
| 892 | Salt Marshes | 39 | 290610.179 | 3059562.933 | 4 |
| 893 | Salt Marshes | 39 | 289785.574 | 3054082.618 | 4 |
| 894 | Salt Marshes | 39 | 290178.895 | 3056080.628 | 4 |
| 895 | Salt Marshes | 39 | 287111.506 | 3068620.298 | 4 |
| 896 | Salt Marshes | 39 | 287394.232 | 3068738.328 | 4 |

c. Socio-Economic Features

| Attribute | Name | Coordinates UTM 1984 | | | Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| Educational Sites | Dammam University | 39 | 419802.9413 | 2920092.316 | 1 |
| Seaport Facilities | King Abdulaziz Seaport | 39 | 420126.4854 | 2928096.346 | 4 |
| Seaport Facilities | Zamil Shipyard | 39 | 421849.4447 | 2930237.373 | 4 |
| Park | Coral Island | 39 | 410843.9247 | 2929605.496 | 3 |
| Hospital | Kahhal Medical Center | 39 | 409741.5188 | 2928475.996 | 2 |
| Park | Saihat Lake | 39 | 406983.7906 | 2927731.551 | 3 |
| Park | Sea Club Resort | 39 | 407413.1583 | 2928710.157 | 3 |
| Commerce area | Qatif City Mall | 39 | 404173.5114 | 2937792.646 | 2 |
| Hospital | Darin PHC Clinic | 39 | 408113.3553 | 2936881.085 | 2 |
| Municipality | Municipality of Tarout | 39 | 408732.1551 | 2938226.668 | 3 |
| Commerce area | Aldokhalh Festival Market | 39 | 409274.7876 | 2939383.52 | 2 |
| Hospital | Mouwasat Hospital | 39 | 402870.5389 | 2939884.611 | 2 |
| Park | Almushari Corniche Park | 39 | 402589.9815 | 2939951.44 | 3 |
| Airport | Ras Tanura Airport | 39 | 403591.9249 | 2955909.16 | 1 |
| Beach | Surfside Golf Club | 39 | 409727.2017 | 2954532.088 | 4 |
| Water discharge | Aramco Sewage Water Treatment Plant | 39 | 404571.2829 | 2954144.598 | 3 |
| Beach | Ras Tanura Beach | 39 | 405428.1027 | 2959413.17 | 4 |
| Water supply | Saline Water Conversion Plant | 39 | 376383.4827 | 2977068.085 | 5 |
| Commerce area | Jubail Commercial Port | 39 | 368243.2019 | 2989448.752 | 2 |
| Hospital | Jubail General Hospital | 39 | 367024.358 | 2986499.353 | 2 |
| Commerce area | Jubail Fish Market | 39 | 367566.9778 | 2987272.009 | 2 |
| Hotel | Golden Tulip Al Jubail Hotel | 39 | 367620.7783 | 2988455.336 | 1 |
| Seaport Facilities | Jubail Commercial Port | 39 | 368257.3543 | 2989454.696 | 4 |
| Water supply | Saline Water Conversion Corporation | 39 | 366034.0861 | 2988421.037 | 5 |
| Educational Sites | Indian International School | 39 | 365122.4847 | 2989539.624 | 1 |
| Park | Jubail Chorniche Park | 39 | 364803.8692 | 2991016.586 | 3 |
| Industrial area | Saudi Aramco Shell Refinery | 39 | 361839.0866 | 2992606.525 | 3 |
| Industrial area | Farabi Petrochemicals Company | 39 | 362712.2845 | 2991714.992 | 3 |
| Industrial area | Sadaf - Saudi Petrochemical Company | 39 | 360471.1718 | 2993857.076 | 3 |
| Industrial area | Eastern Petrochemical Company - Sharq | 39 | 359822.2004 | 2992924.369 | 3 |
| Seaport Facilities | King Fahd Industrial Port | 39 | 369918.4844 | 2996411.822 | 4 |
| Industrial area | Jubail O & M Company Limited | 39 | 361991.9318 | 2994946.888 | 3 |
| Educational Sites | Jubail Industrial College | 39 | 358251.2917 | 2999229.938 | 1 |
| Beach | Al Nakheel Beach | 39 | 358467.6071 | 3000256.992 | 4 |

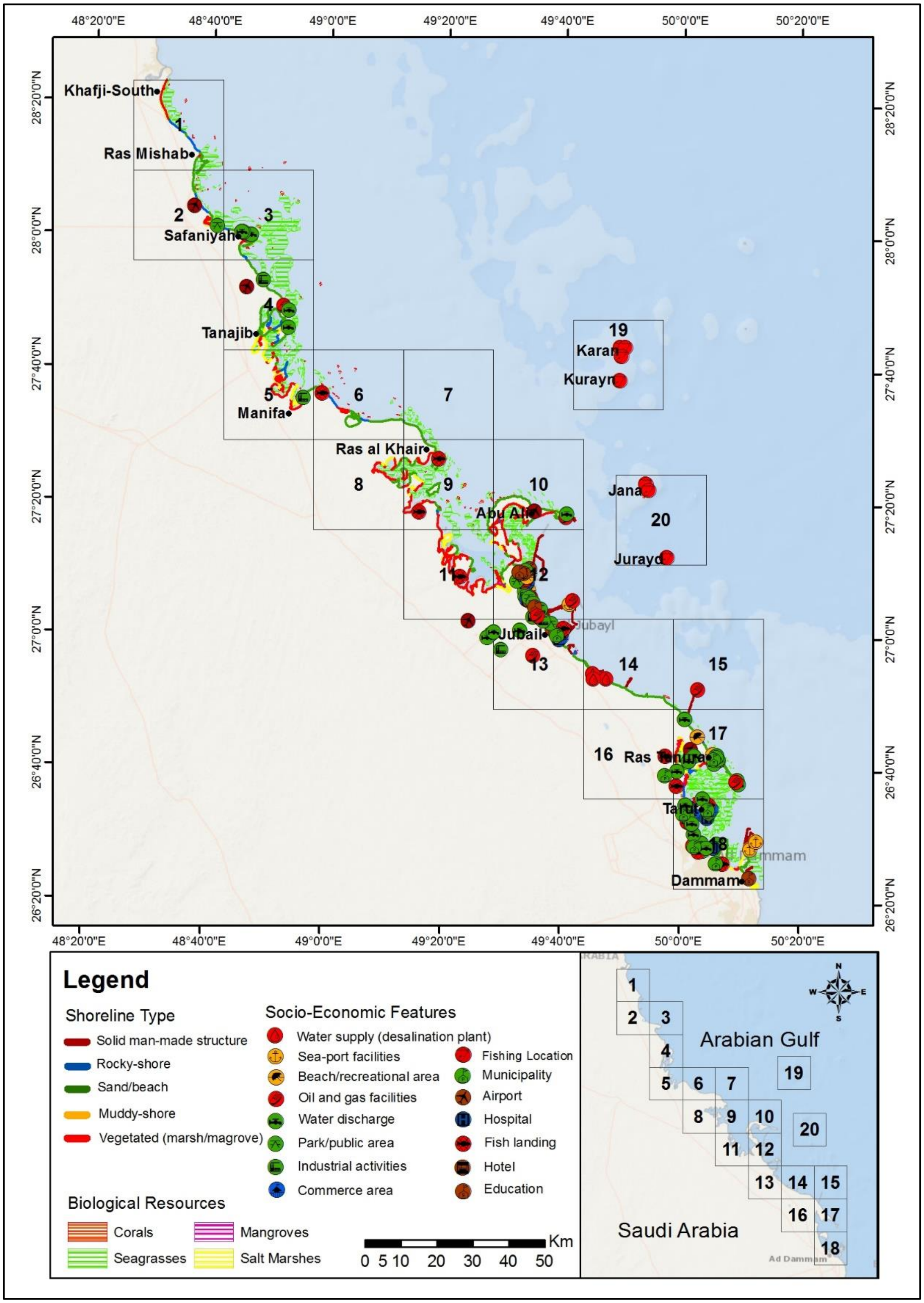
| Attribute | Name | Coordinates UTM 1984 | | | Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| Park | Aqua Park | 39 | 357404.7266 | 2999921.99 | 3 |
| Commerce area | Fanateer Mall | 39 | 357990.88 | 3002225.944 | 2 |
| Industrial area | Saudi Basic Industries Corporation (SABIC) | 39 | 358000.659 | 3002692.063 | 3 |
| Commerce area | Galleria Center Market | 39 | 358126.4234 | 3002429.149 | 2 |
| Hospital | Royal Commission Hospital | 39 | 357727.0557 | 3002984.92 | 2 |
| Educational Sites | Jubail University College - Female Branch | 39 | 357363.8765 | 3002621.898 | 1 |
| Hotel | Karan Hotel | 39 | 357821.5879 | 3003329.302 | 1 |
| Commerce area | Othaim Markets | 39 | 357270.2187 | 3004661.963 | 2 |
| Park | Andalus Park | 39 | 355302.5518 | 3002867.511 | 3 |
| Beach | Dareen Sea Club | 39 | 358918.7397 | 3004981.633 | 4 |
| Beach | Fanateer Cornish Sidewalk | 39 | 358133.3419 | 3003922.603 | 4 |
| Educational Sites | Dana Elementry School | 39 | 358904.7748 | 3006274.561 | 1 |
| Park | Darin Chorniche Park | 39 | 357784.4195 | 3005790.63 | 3 |
| Educational Sites | Fanateer Elementary School | 39 | 357207.3948 | 3004982.223 | 1 |
| Educational Sites | Om Alqurra Secondary School | 39 | 356279.8918 | 3004950.585 | 1 |
| Educational Sites | Jalmudah Elementary School | 39 | 355893.1678 | 3005300.306 | 1 |
| Industrial area | Saudi Aramco - Manifa Camp | 39 | 295928.1417 | 3053900.775 | 3 |
| Airport | Tanajib Airport | 39 | 280284.5468 | 3084741.676 | 1 |
| Park | Prince Sultan Resort and Park | 39 | 272048.7292 | 3101835.505 | 3 |
| Airport | Ras Al-Mishab Airport | 39 | 265734.5983 | 3107323.822 | 1 |
| Industrial area | Saudi Aramco - Tanajib Cam | 39 | 284904.2532 | 3086778.823 | 3 |
| Airport | Jubail Airport | 39 | 341816.5954 | 2991782.838 | 1 |
| Industrial area | Saudi Aramco Total Refining and Petrochemical | 39 | 350786.0651 | 2983738.652 | 3 |
| Water discharge | Sewage Treatment Plant 9 | 39 | 348006.0433 | 2988129.874 | 3 |
| Water discharge | Storm Water Holding Pond 2 | 39 | 346956.8988 | 2987137.375 | 3 |
| Water discharge | Storm Water Holding Pond 1 | 39 | 348910.2923 | 2988781.944 | 3 |
| Industrial area | Royal Commission for Jubail and Yanbu | 39 | 357675.1748 | 2998531.068 | 3 |
| Hospital | Almana General Hospital | 39 | 358077.3584 | 2997625.494 | 2 |
| Educational Sites | ISG International School | 39 | 358892.0136 | 2997259.71 | 1 |
| Hotel | InterContinental Al Jubail Hotel | 39 | 359217.0993 | 2998209.869 | 1 |
| Park | Huwaylat Recreation Center | 39 | 358714.2518 | 2998199.936 | 3 |
| Park | Shabab Marine Park | 39 | 359962.6437 | 2996785.74 | 3 |
| Educational Sites | Jubail University College | 39 | 360292.2135 | 2995601.644 | 1 |
| Water discharge | Industrial Wastewater Treatment Plant | 39 | 356117.6433 | 2989244.761 | 3 |
| Oil and gas facilities | Berri Gas Plant | 39 | 359711.1687 | 2982056.035 | 5 |
| Water supply | Saihat Saline Water Conversion Plant | 39 | 404282.9354 | 2929147.544 | 5 |

| Attribute | Name | Coordinates UTM 1984 | | | Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| Water supply | Saihat Water Intake | 39 | 406553.8091 | 2929957.309 | 5 |
| Water supply | SWCC Water Intake | 39 | 380064.388 | 2975665.256 | 5 |
| Airport | Abu Ali Airport | 39 | 360270.7314 | 3022276.025 | 1 |
| Oil and gas facilities | GOSP Safaniyah (SFNY-1) | 39 | 279853.1135 | 3099447.918 | 5 |
| Oil and gas facilities | Tanajib Terminal Facilities | 39 | 290553.7455 | 3079429.235 | 5 |
| Oil and gas facilities | GOSP Berri (BRRI) | 39 | 369071.0113 | 3020490.492 | 5 |
| Oil and gas facilities | Jubail Terminal | 39 | 370879.1135 | 2997338.426 | 5 |
| Oil and gas facilities | Jubail Refinary | 39 | 360988.751 | 2993231.317 | 5 |
| Oil and gas facilities | Metering and Control Platform | 39 | 402931.3804 | 2977779.825 | 5 |
| Oil and gas facilities | NGL Loading Facility | 39 | 405633.1197 | 2972620.989 | 5 |
| Fish Landing | Safaniya | 39 | 279085.1443 | 3100104.312 | 5 |
| Fish Landing | Manifa | 39 | 301181.2931 | 3055221.51 | 5 |
| Fish Landing | AlBdeea | 39 | 333635.0117 | 3036923.137 | 5 |
| Fish Landing | AlNagourieah | 39 | 328110.9745 | 3022077.287 | 5 |
| Fish Landing | Fanateer | 39 | 339504.3013 | 3004124.166 | 5 |
| Fish Landing | Jubail | 39 | 368160.2443 | 2989623.568 | 5 |
| Fish Landing | Safwa | 39 | 396470.935 | 2954062.579 | 5 |
| Fish Landing | Ramis | 39 | 399578.2059 | 2945776.523 | 5 |
| Fish Landing | Dareen | 39 | 408554.7664 | 2940597.738 | 5 |
| Fish Landing | Qateef | 39 | 402685.4768 | 2935764.205 | 5 |
| Fish Landing | Syhat | 39 | 405792.7477 | 2927478.15 | 5 |
| Fish Landing | Dammam | 39 | 412352.5419 | 2924025.626 | 5 |
| Water supply | Jubail Desalination Plant | 39 | 376519.0072 | 2975565.273 | 5 |
| Water discharge | South Anak | 39 | 406544.869 | 2929947.848 | 3 |
| Water discharge | North Anak | 39 | 404340.3672 | 2932389.927 | 3 |
| Water discharge | Majidia | 39 | 403703.698 | 2935186.046 | 3 |
| Water discharge | North Nasira | 39 | 402111.3243 | 2940614.735 | 3 |
| Water discharge | Dammam STP | 39 | 407947.2655 | 2928585.24 | 3 |
| Water discharge | Jaruadiyah STP | 39 | 402674.3029 | 2937387.058 | 3 |
| Water discharge | Awamiya STP | 39 | 402111.3243 | 2940614.735 | 3 |
| Water discharge | Al Jesh STP | 39 | 403913.503 | 2935262.004 | 3 |
| Water discharge | Sanabis STP | 39 | 406853.6902 | 2942218.565 | 3 |
| Water discharge | Safwa STP | 39 | 399775.0448 | 2949992.996 | 3 |
| Water discharge | Rahima STP | 39 | 402940.7307 | 2952719.207 | 3 |
| Water discharge | Refinery Discharge | 39 | 410595.82 | 2953826.13 | 3 |
| Water discharge | Refinery Discharge | 39 | 411335.59 | 2952871.5 | 3 |
| Water discharge | Refinery old Discharge | 39 | 410107.8979 | 2951946.366 | 3 |
| Water discharge | Refinery intake | 39 | 410915.78 | 2954245.4 | 3 |
| Water discharge | Combined Outfall | 39 | 401924.2577 | 2964374.58 | 3 |

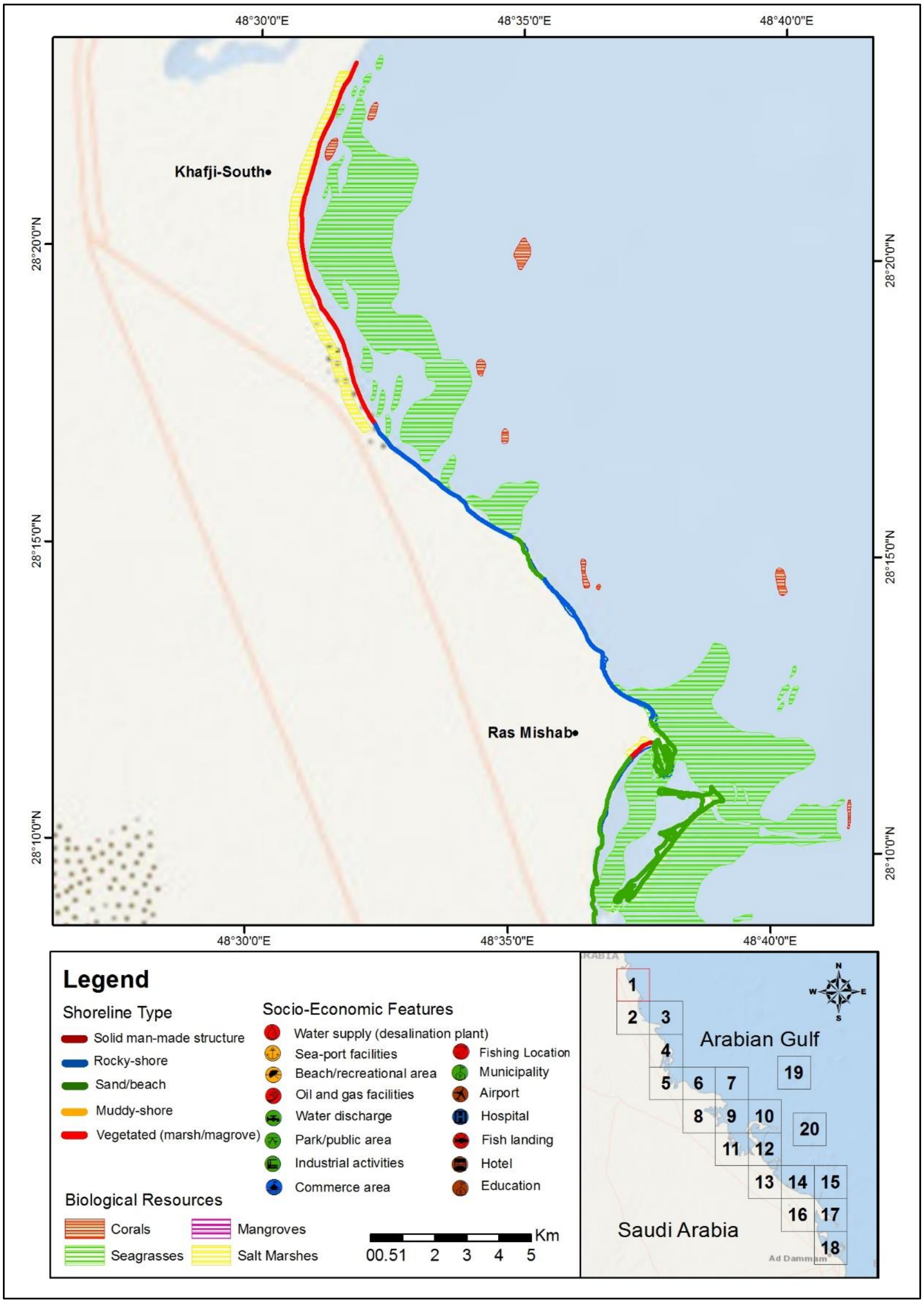
| Attribute | Name | Coordinates UTM 1984 | | | Score |
|---|---|---|---|---|---|
| | | Zone | Easting | Northing | |
| Water discharge | Cooling Water Module 4 | 39 | 401994.2395 | 2964333.544 | 3 |
| Water discharge | Tanajib Marine STP | 39 | 291703.9236 | 3073439.197 | 3 |
| Water discharge | Rahima Community STP | 39 | 402942.2801 | 2952712.522 | 3 |
| Water discharge | Abu Ali | 39 | 369227.7554 | 3021527.132 | 3 |
| Water discharge | Cooling Water (Outfall Plant) | 39 | 411124.9972 | 2953146.319 | 3 |
| Water discharge | Gulf Utility | 39 | 410666.7553 | 2953818.863 | 3 |
| Water discharge | Safaniyah STP | 39 | 281526.572 | 3099379.296 | 3 |
| Water discharge | Desalter Reject | 39 | 279237.497 | 3099958.393 | 3 |
| Water discharge | Hypochlorinator Overflow | 39 | 278870.3548 | 3100045.343 | 3 |
| Water discharge | Tanajib Utilities Reject | 39 | 291894.0579 | 3078209.116 | 3 |
| Water discharge | Qurayyah Hypochlorinator | 39 | 410489.8007 | 2864071.474 | 3 |
| Water discharge | Qurayyah Basin Effluent | 39 | 410431.3515 | 2864264.559 | 3 |
| Water discharge | Qurayyah Basin D | 39 | 410583.3599 | 2863898.547 | 3 |
| Water discharge | RO Reject | 39 | 416551.3334 | 2947361.245 | 3 |
| Water discharge | South STP | 39 | 416893.4136 | 2946313.518 | 3 |
| Municipality | Al Jubayl | 39 | 366422.4567 | 2987674.665 | 3 |
| Municipality | Al Qatif | 39 | 401504.0132 | 2937949.284 | 3 |
| Municipality | Ra's Tannurah | 39 | 409959.6827 | 2953176.398 | 3 |
| Municipality | Safwah | 39 | 396421.6876 | 2948664.295 | 3 |
| Municipality | Sayhat | 39 | 404606.2638 | 2928850.638 | 3 |
| Municipality | Tarut | 39 | 408167.4234 | 2938980.349 | 3 |
| Municipality | Dammam | 39 | 410506.797 | 2924183.816 | 3 |

Appendix B

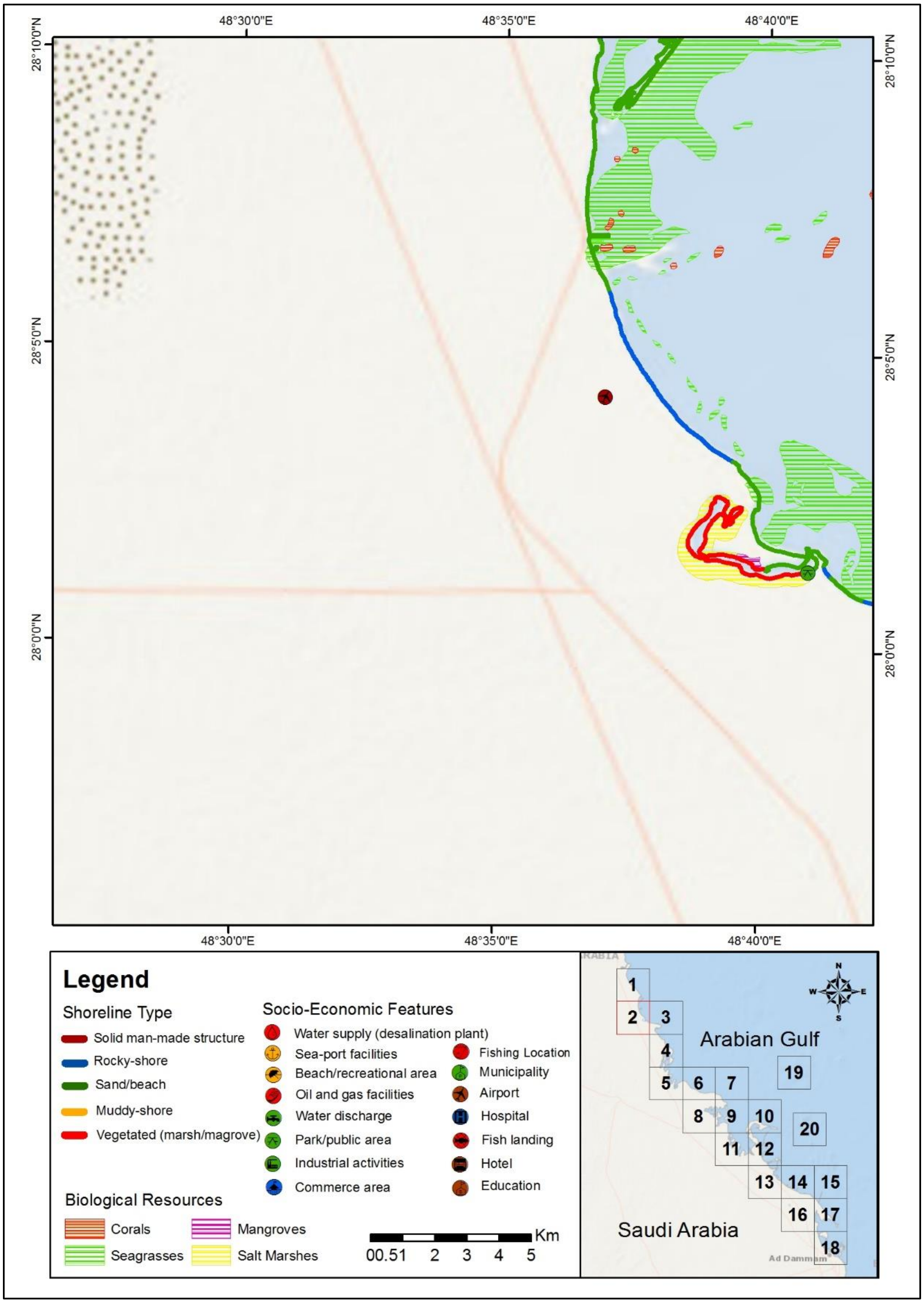
Complete ESI Map for all grid zones in the Western Arabian Gulf



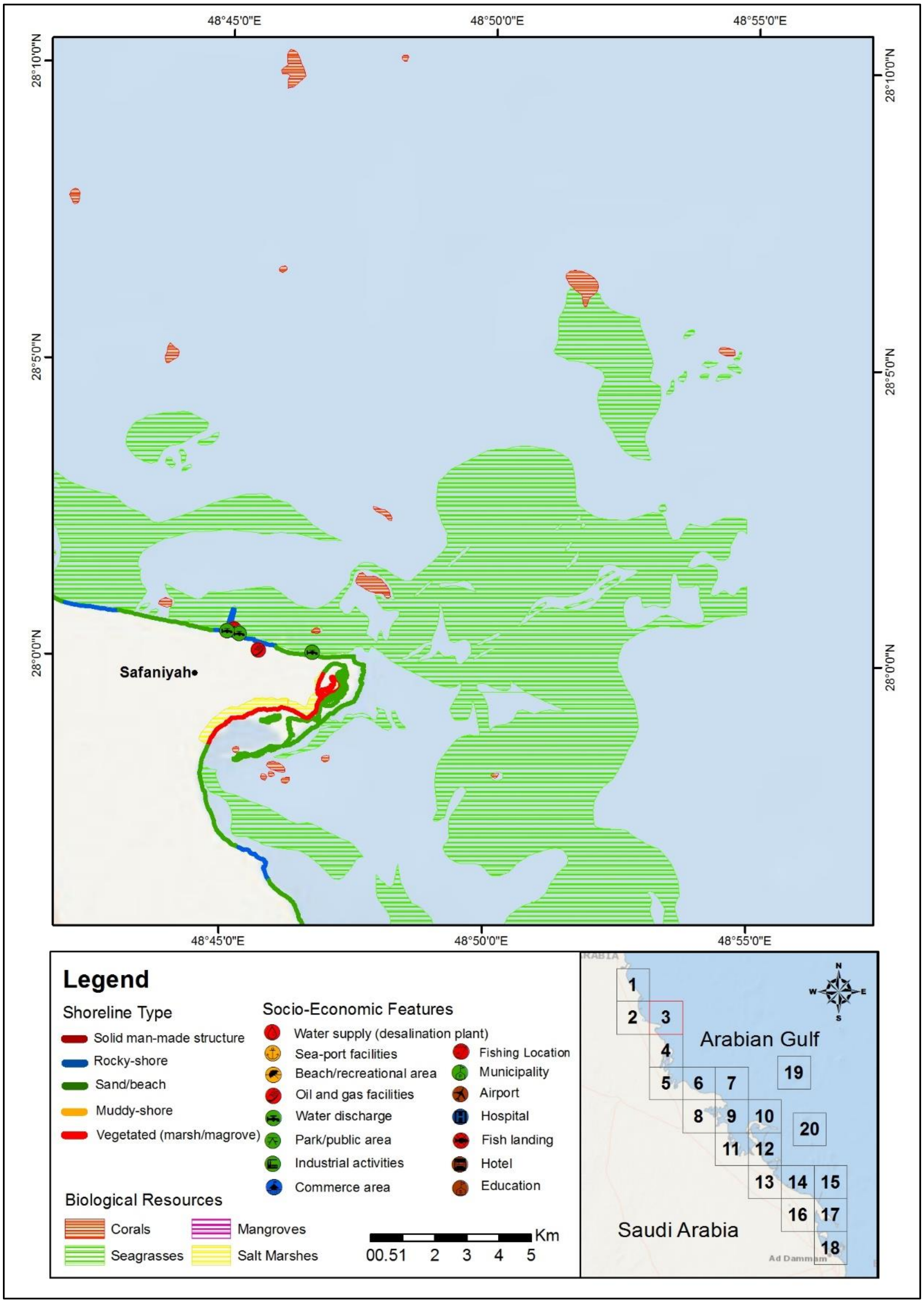
- Grid 1


48°30'0"E
48°35'0"E
48°40'0"E
28°20'0"N
28°15'0"N
28°10'0"N
Khafji-South
Ras Mishab
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
0 0.5 1 2 3 4 5
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 2


48°30'0"E
48°35'0"E
48°40'0"E
28°10'0"N
28°5'0"N
28°0'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Seagrasses
Mangroves
Salt Marshes
00.51 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
N S E W

- Grid 3


48°45'0"E
48°50'0"E
48°55'0"E
28°10'0"N
28°5'0"N
28°0'0"N
Safaniyah
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
00.51 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1
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17
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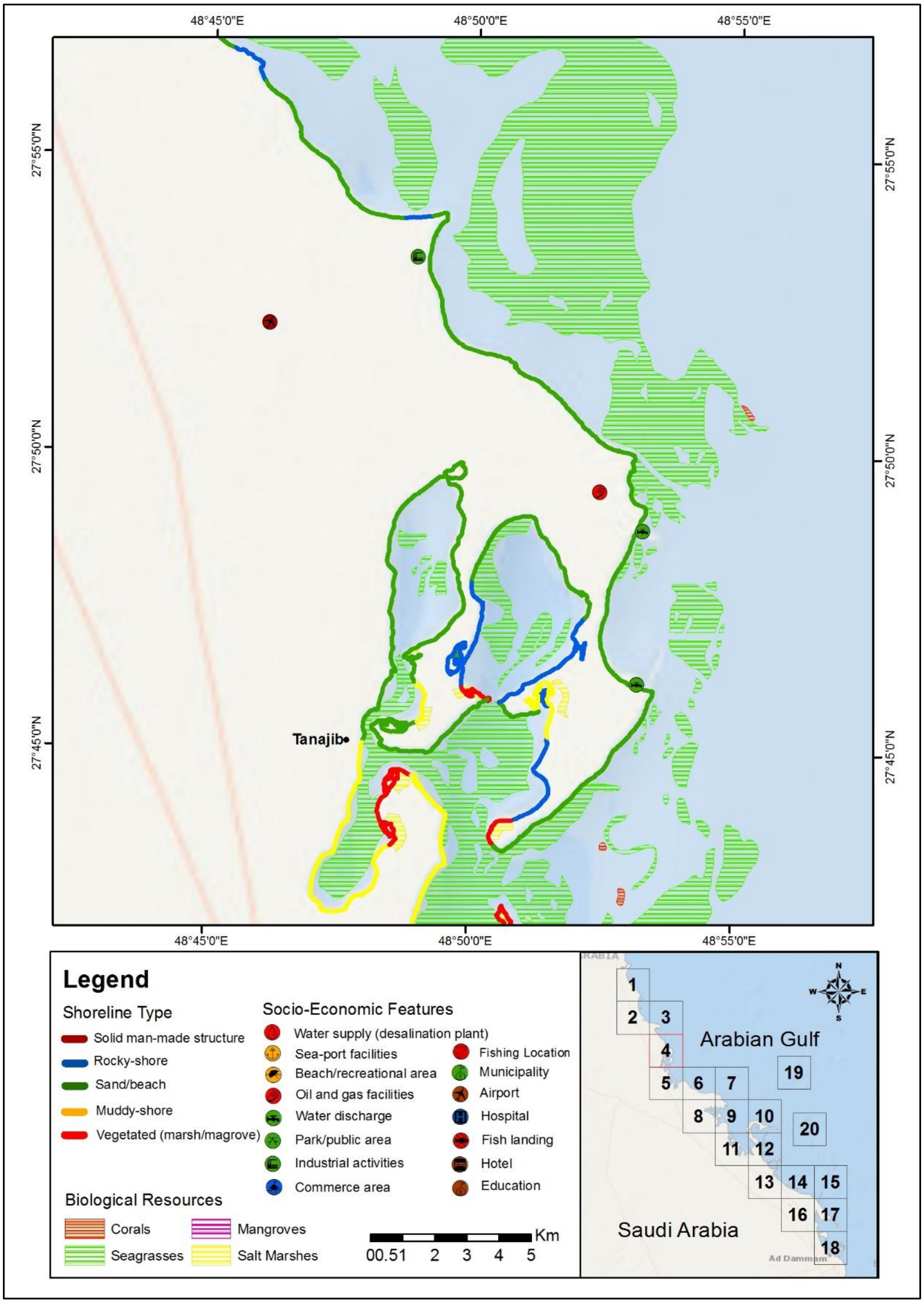
- Grid 4


48°45'0"E
48°50'0"E
48°55'0"E
27°55'0"N
27°50'0"N
27°45'0"N
Tanajib
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
0 0.5 1 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1
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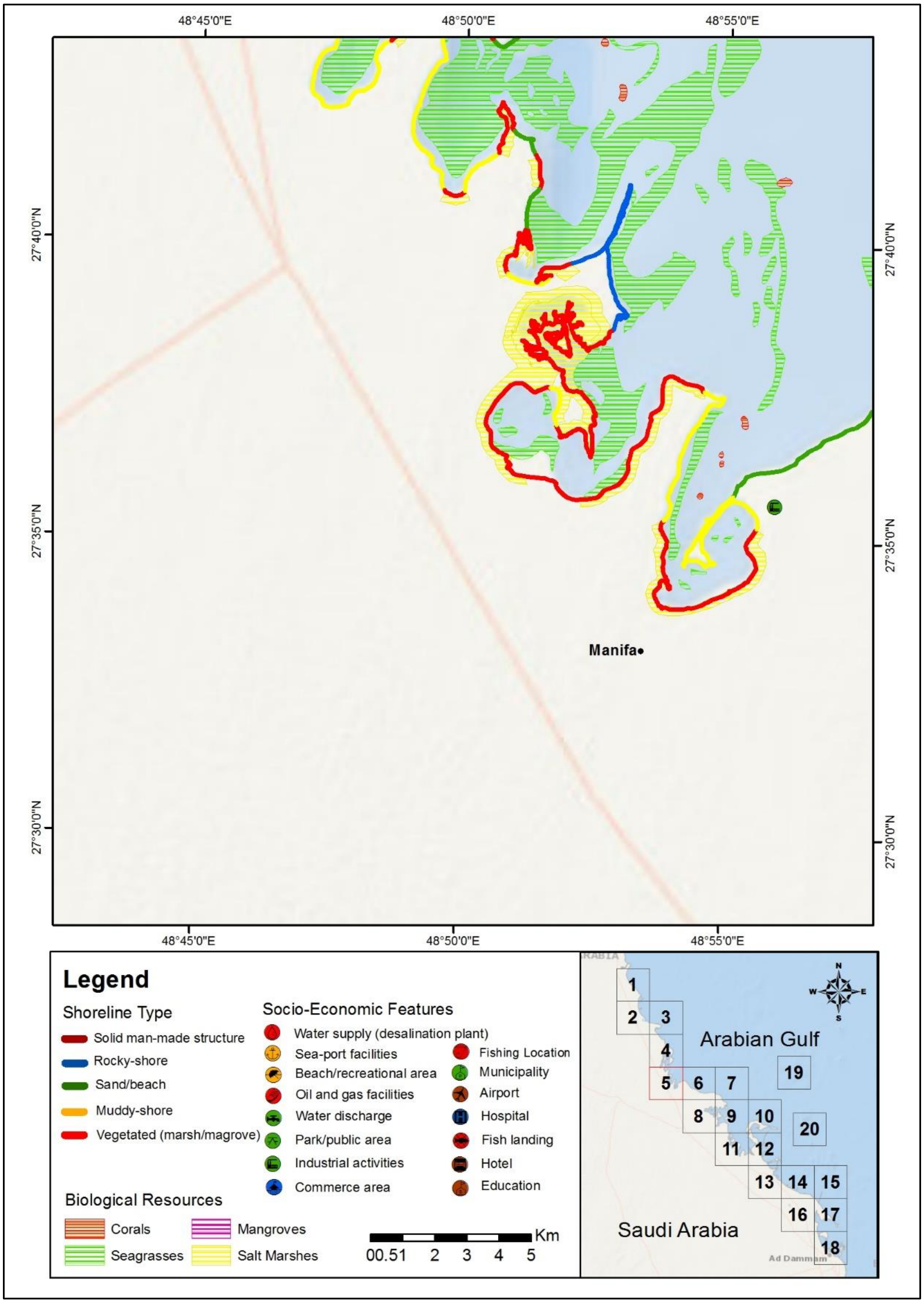
19
20

- Grid 5


48°45'0"E
48°50'0"E
48°55'0"E
27°40'0"N
27°35'0"N
27°30'0"N
Manifa
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
00.51 2 3 4 5
Km
Arabian Gulf
Saudi Arabia
1
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3
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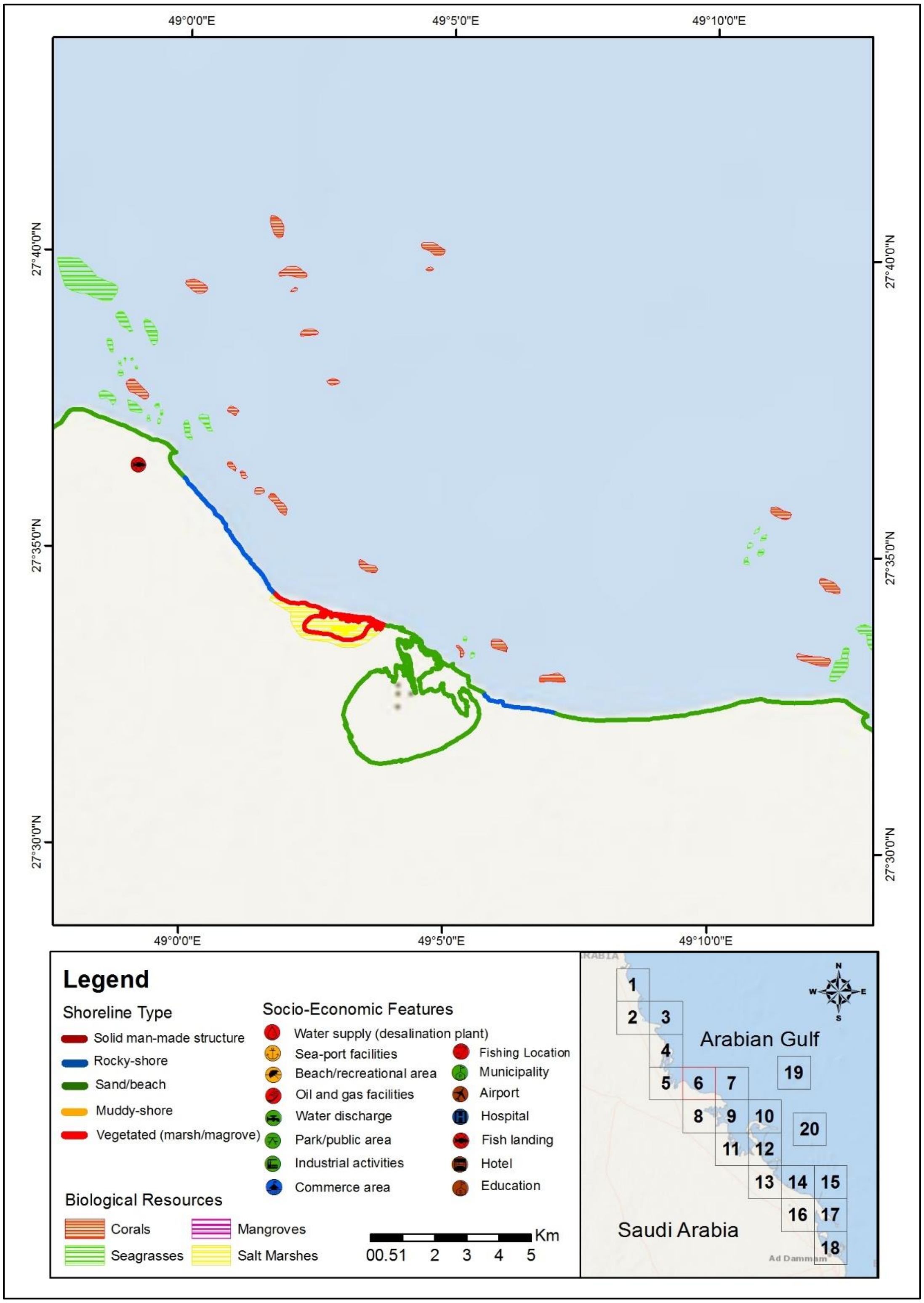
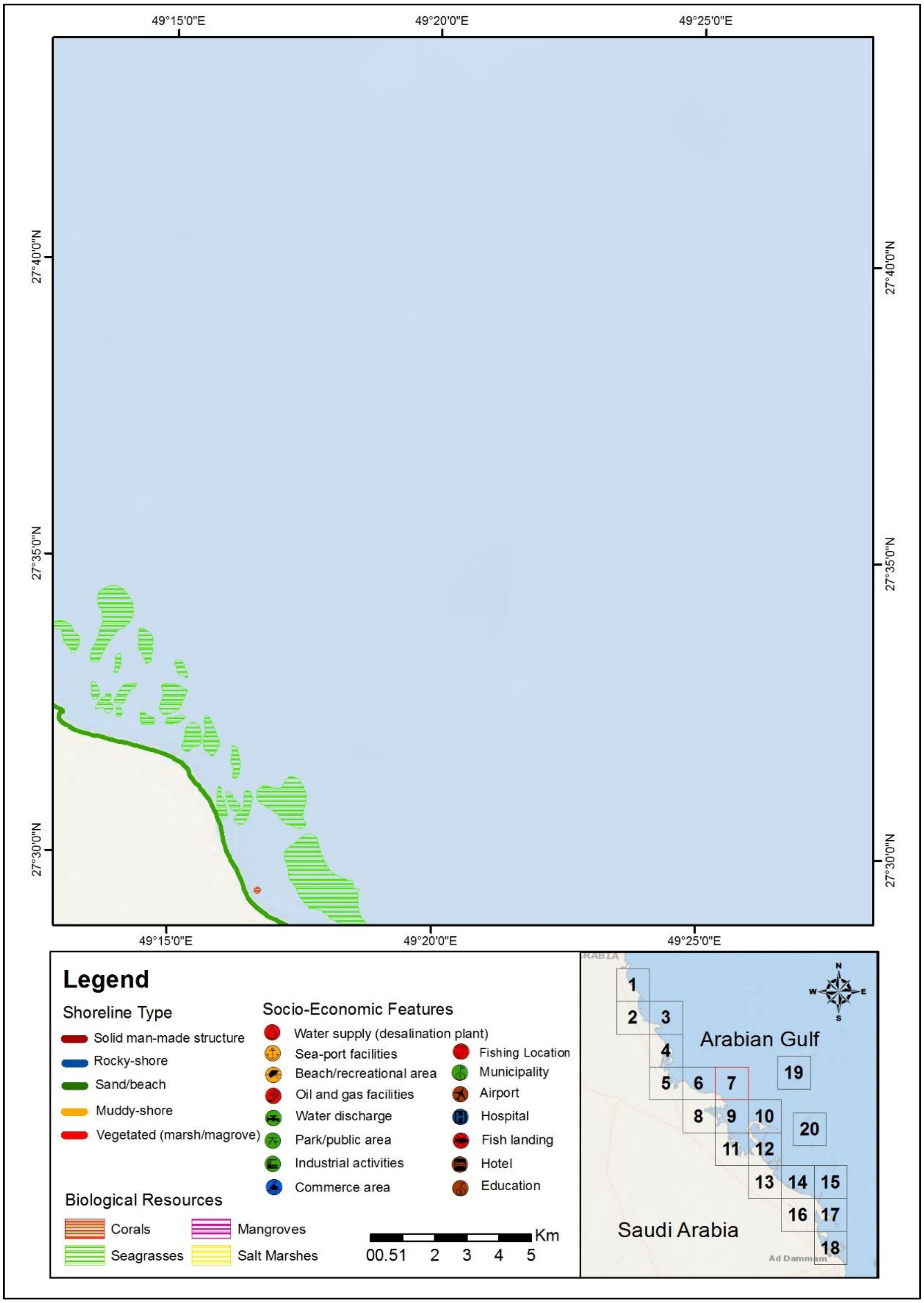
19
20

- Grid 6

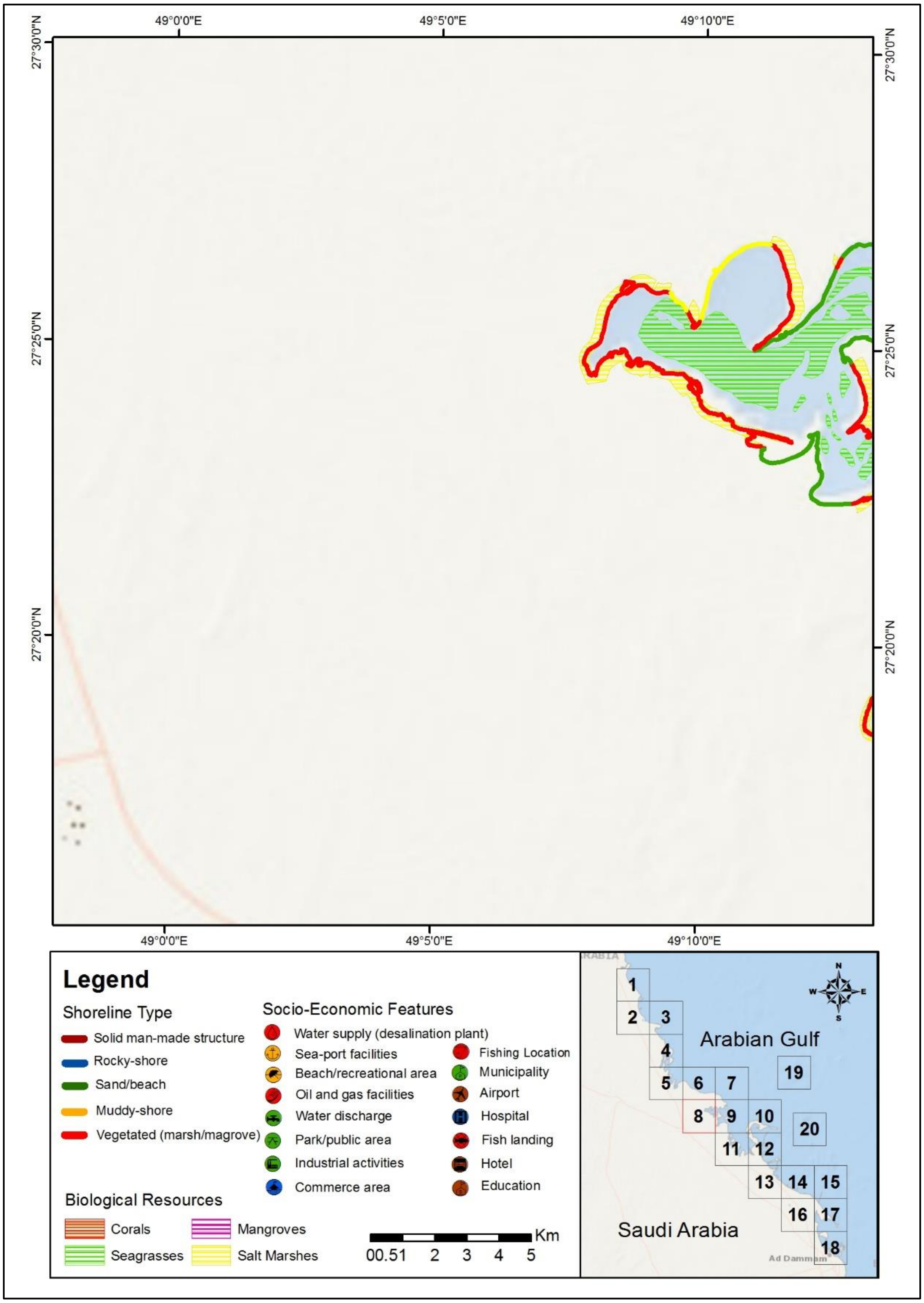


49°0'0"E
49°5'0"E
49°10'0"E
27°40'0"N
27°35'0"N
27°30'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Seagrasses
Mangroves
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
Ad Dammam
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 7

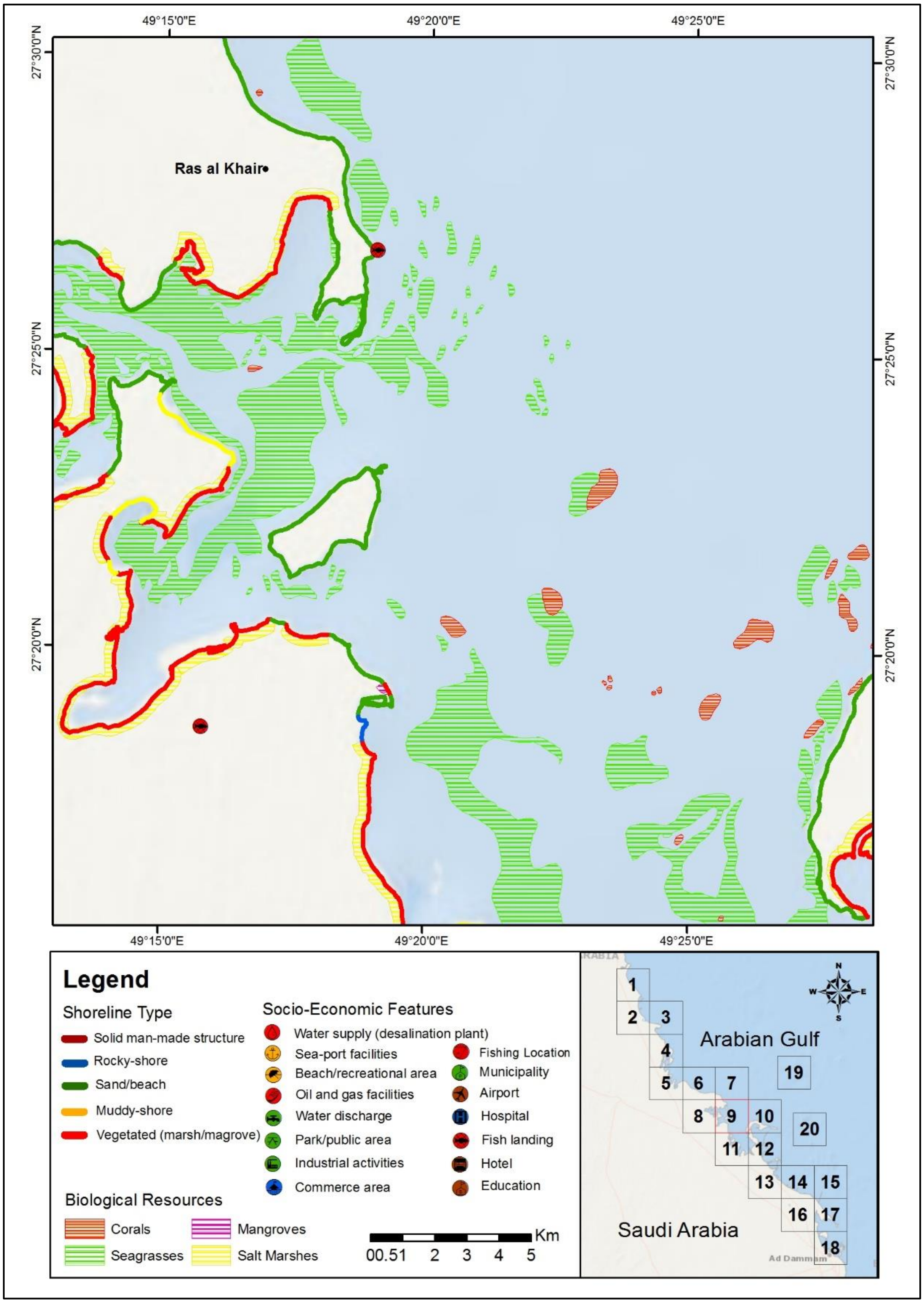

49°15'0"E
49°20'0"E
49°25'0"E
27°40'0"N
27°35'0"N
27°30'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
N S W E

- Grid 8



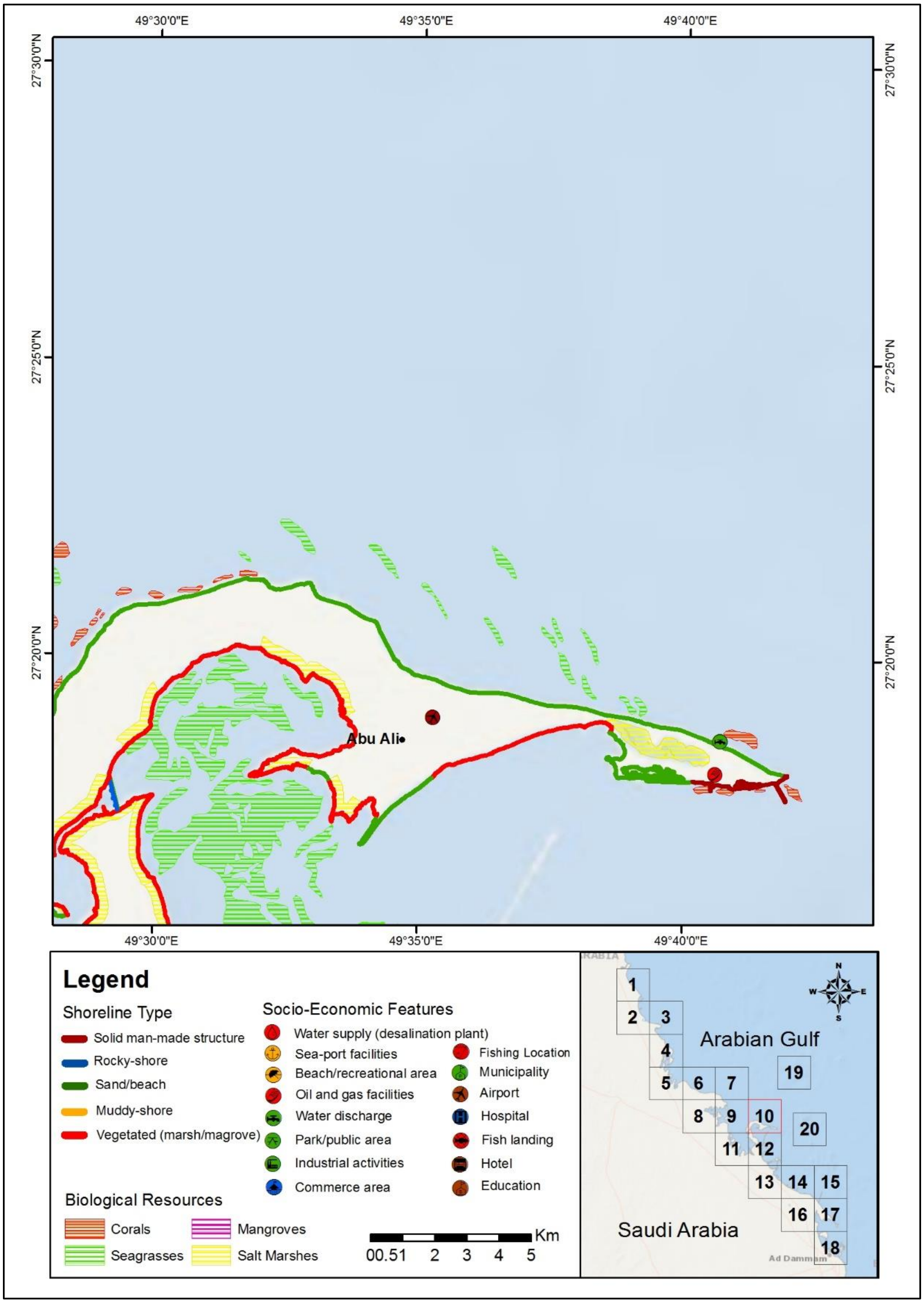
49°0'0"E
49°5'0"E
49°10'0"E
27°30'0"N
27°25'0"N
27°20'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
0 0.5 1 2 3 4 5
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 9



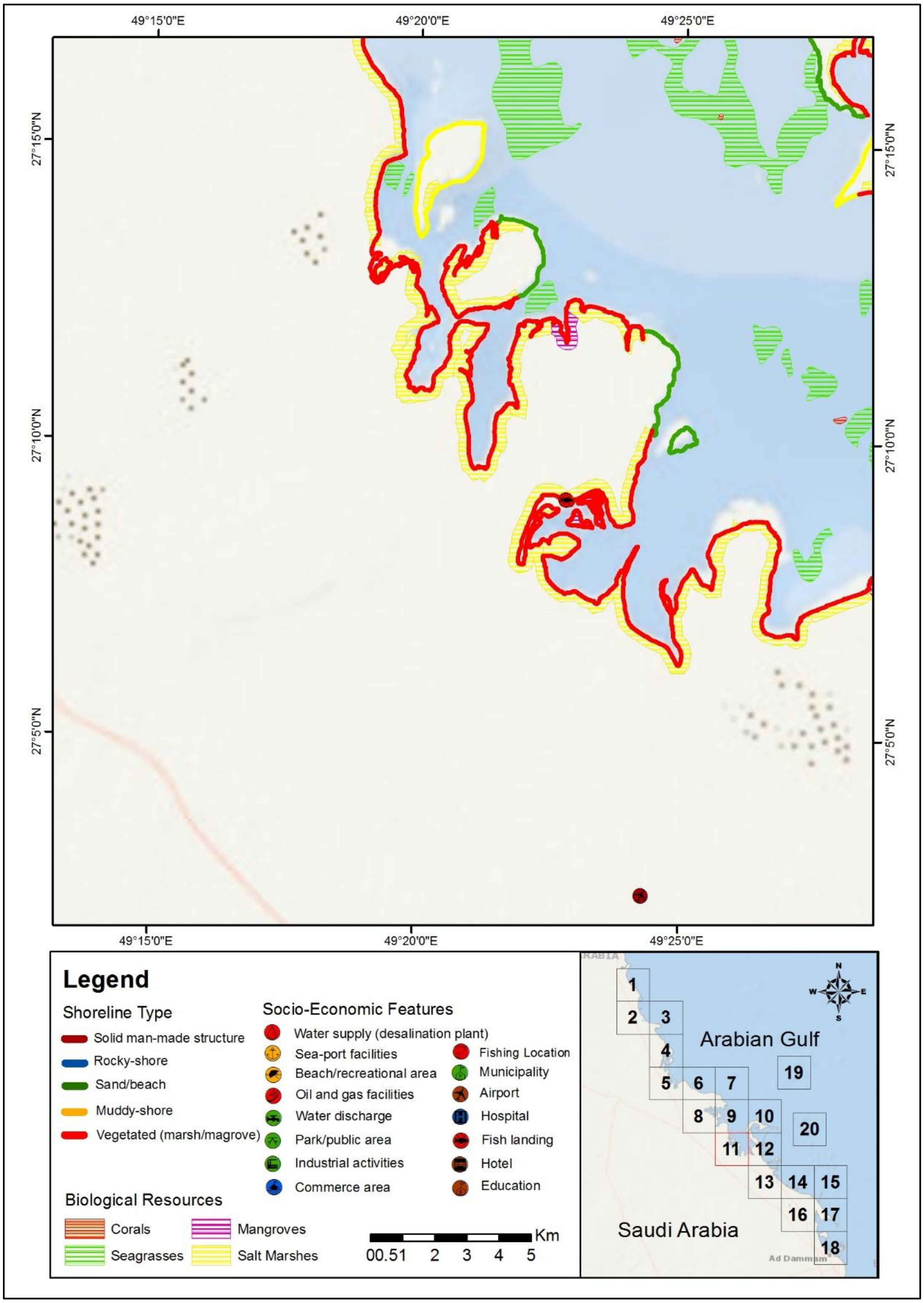
49°15'0"E
49°20'0"E
49°25'0"E
27°30'0"N
27°25'0"N
27°20'0"N
Ras al Khair
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Seagrasses
Mangroves
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
1
2 3
4
5 6 7
8 9 10
11 12
13 14 15
16 17
18
19
20

- Grid 10

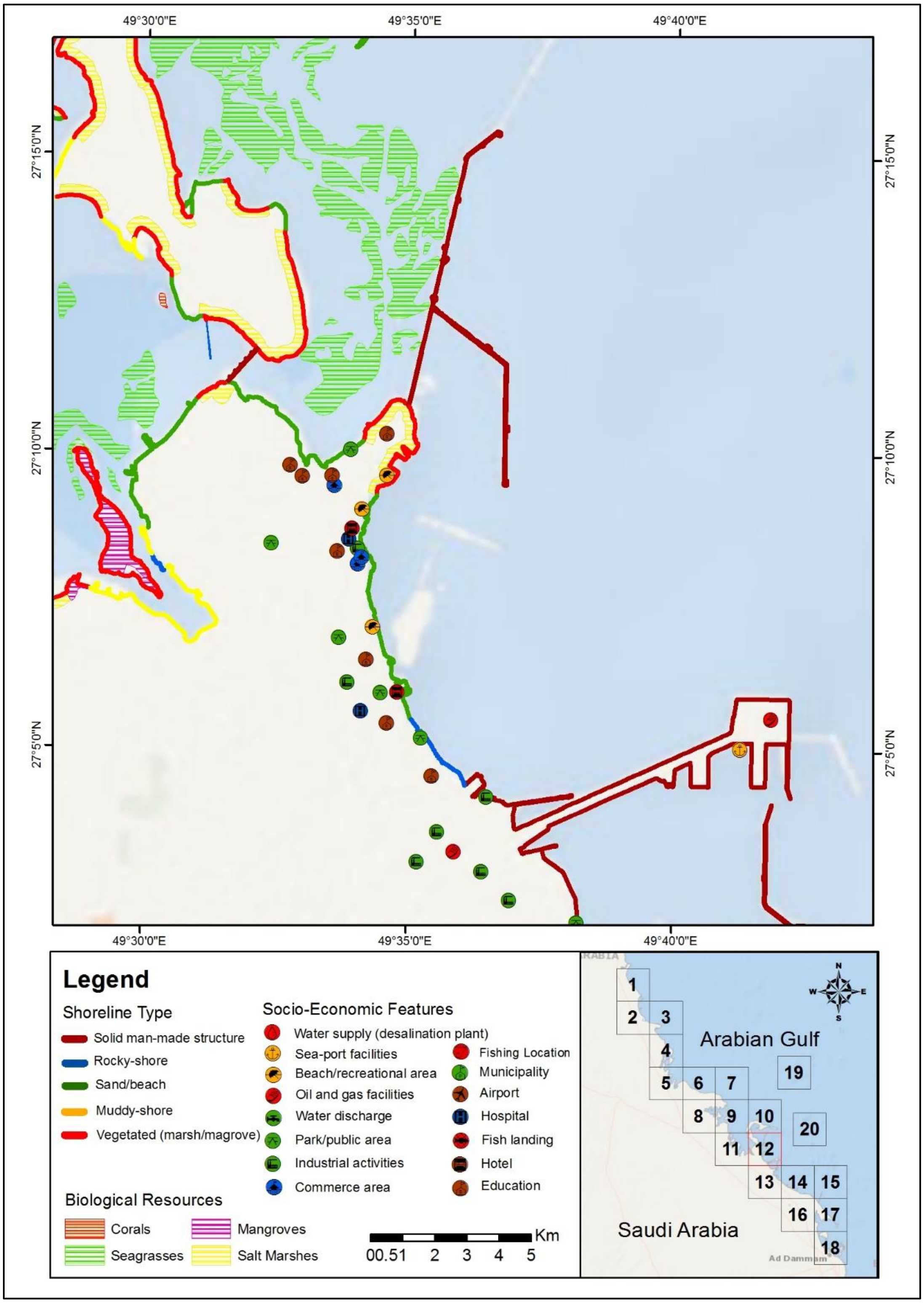


49°30'0"E
49°35'0"E
49°40'0"E
27°30'0"N
27°25'0"N
27°20'0"N
Abu Ali
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Seagrasses
Mangroves
Salt Marshes
00.51 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

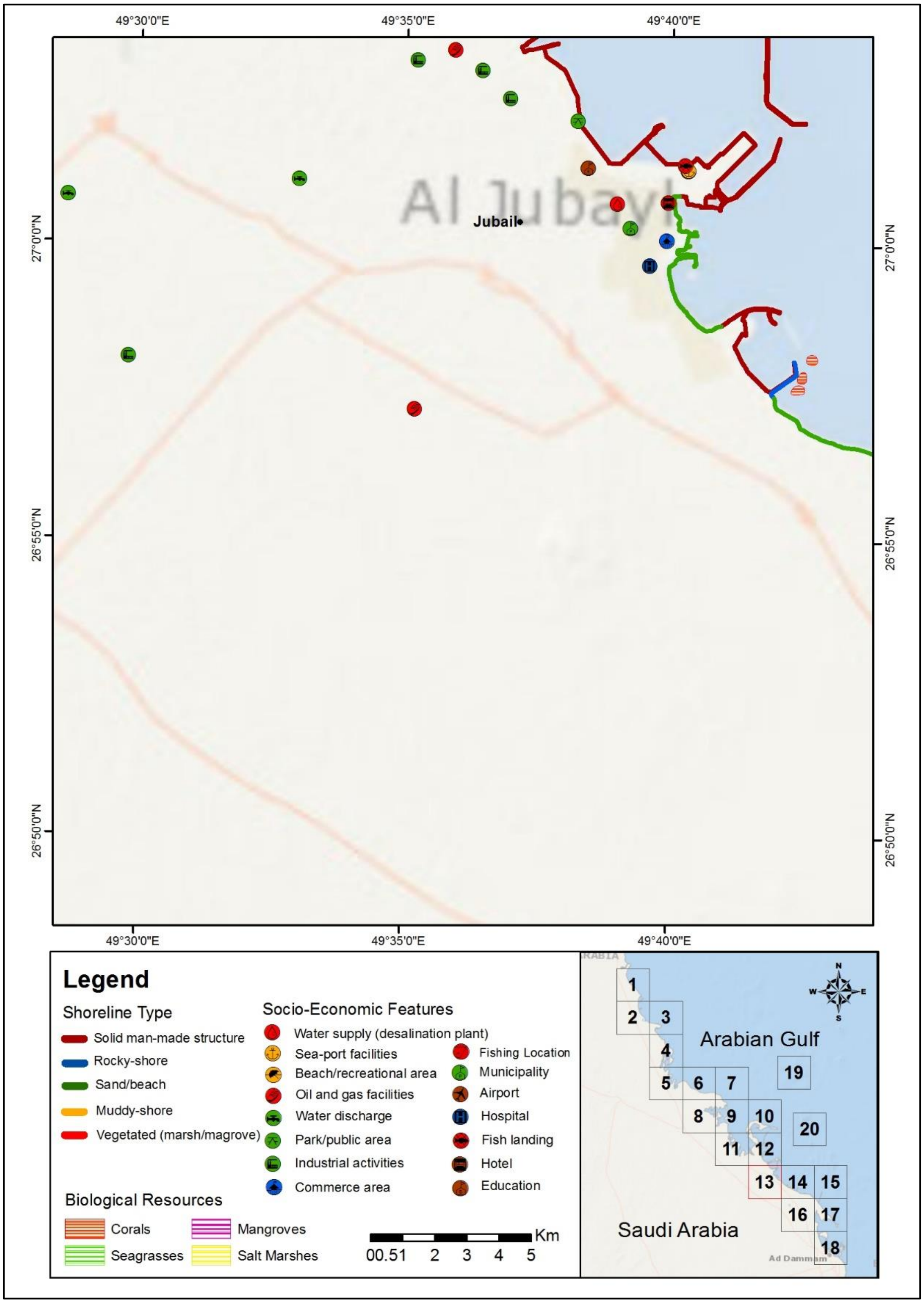
* Grid 11


49°15'0"E
49°20'0"E
49°25'0"E
27°15'0"N
27°10'0"N
27°5'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
1
2 3
4
5 6 7
19
8 9 10
20
11 12
13 14 15
16 17
18

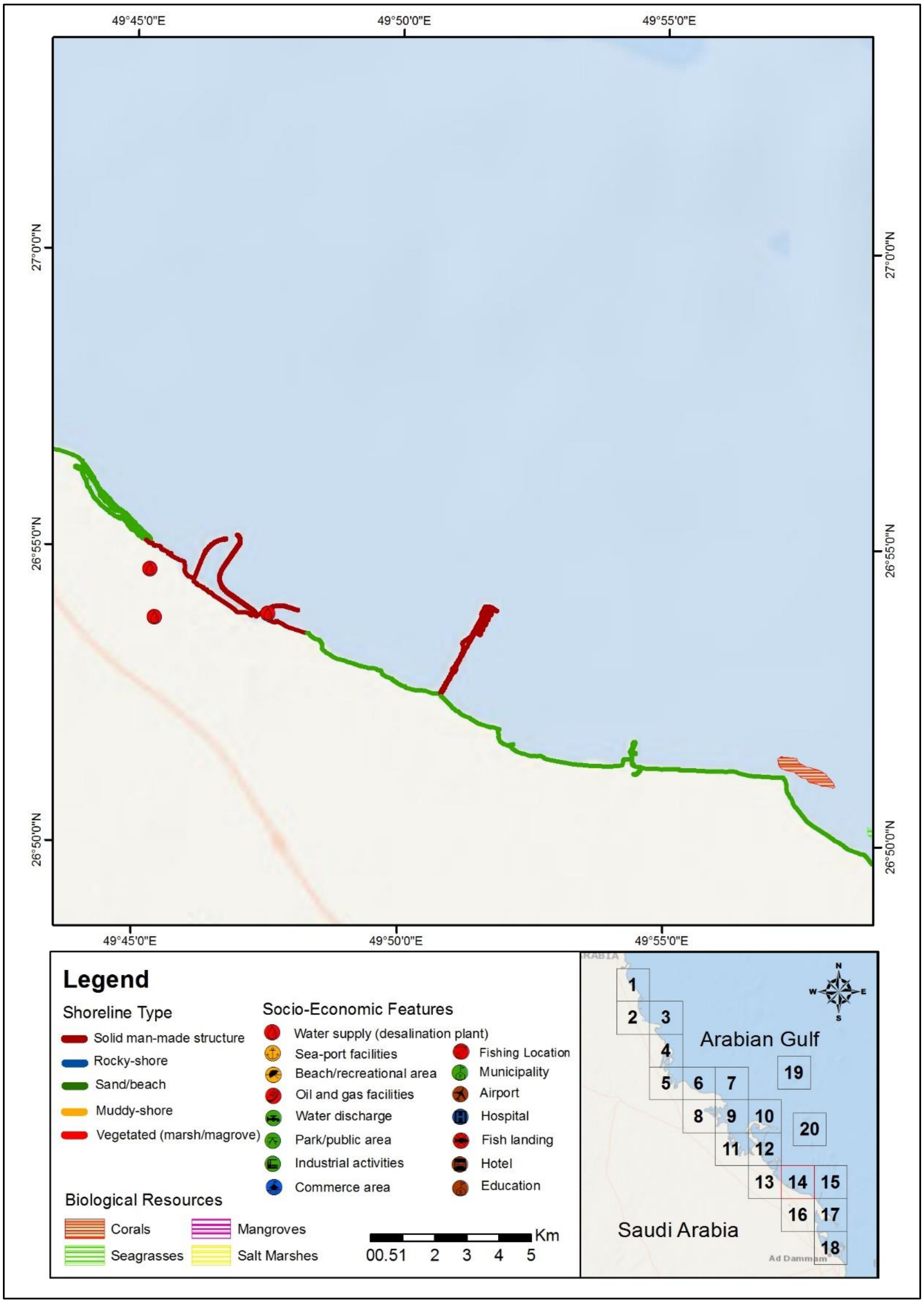
- Grid 12


49°30'0"E
49°35'0"E
49°40'0"E
27°15'0"N
27°10'0"N
27°5'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Seagrasses
Mangroves
Salt Marshes
00.51 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

• Grid 13

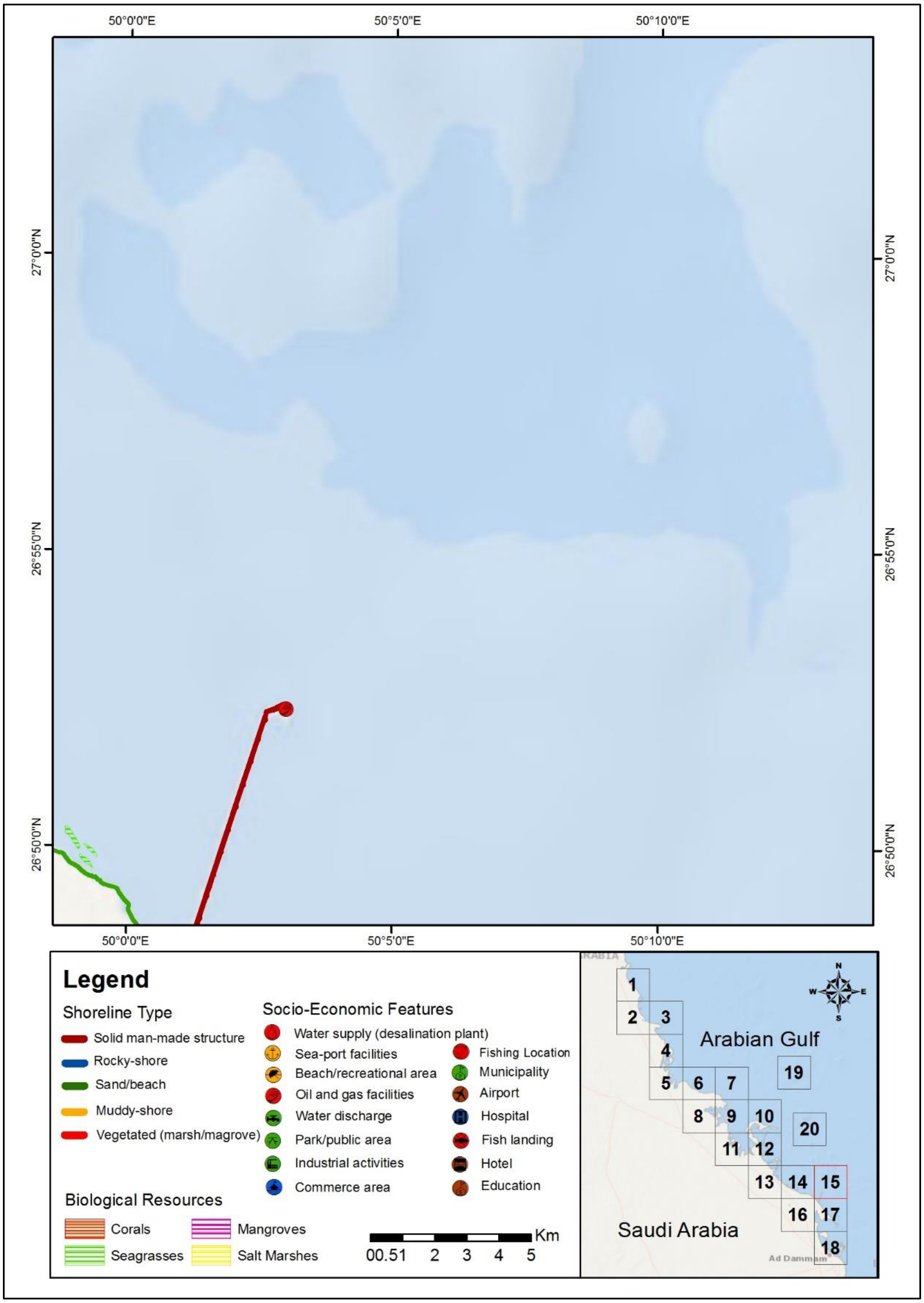

49°30'0"E
49°35'0"E
49°40'0"E
27°0'0"N
26°55'0"N
26°50'0"N
Al Jubayl
Jubail
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
00.51 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 14



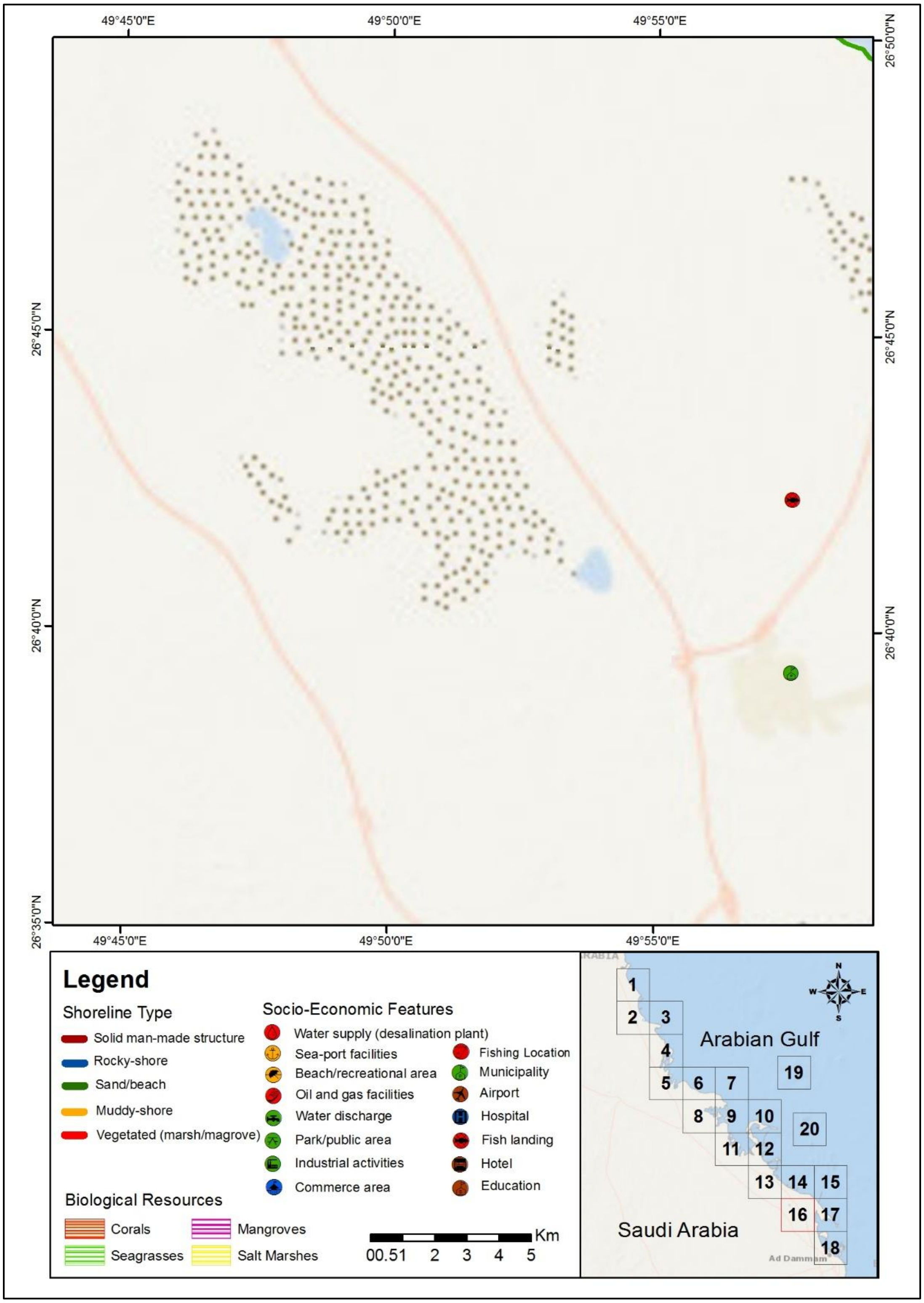
49°45'0"E
49°50'0"E
49°55'0"E
27°0'0"N
26°55'0"N
26°50'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 15

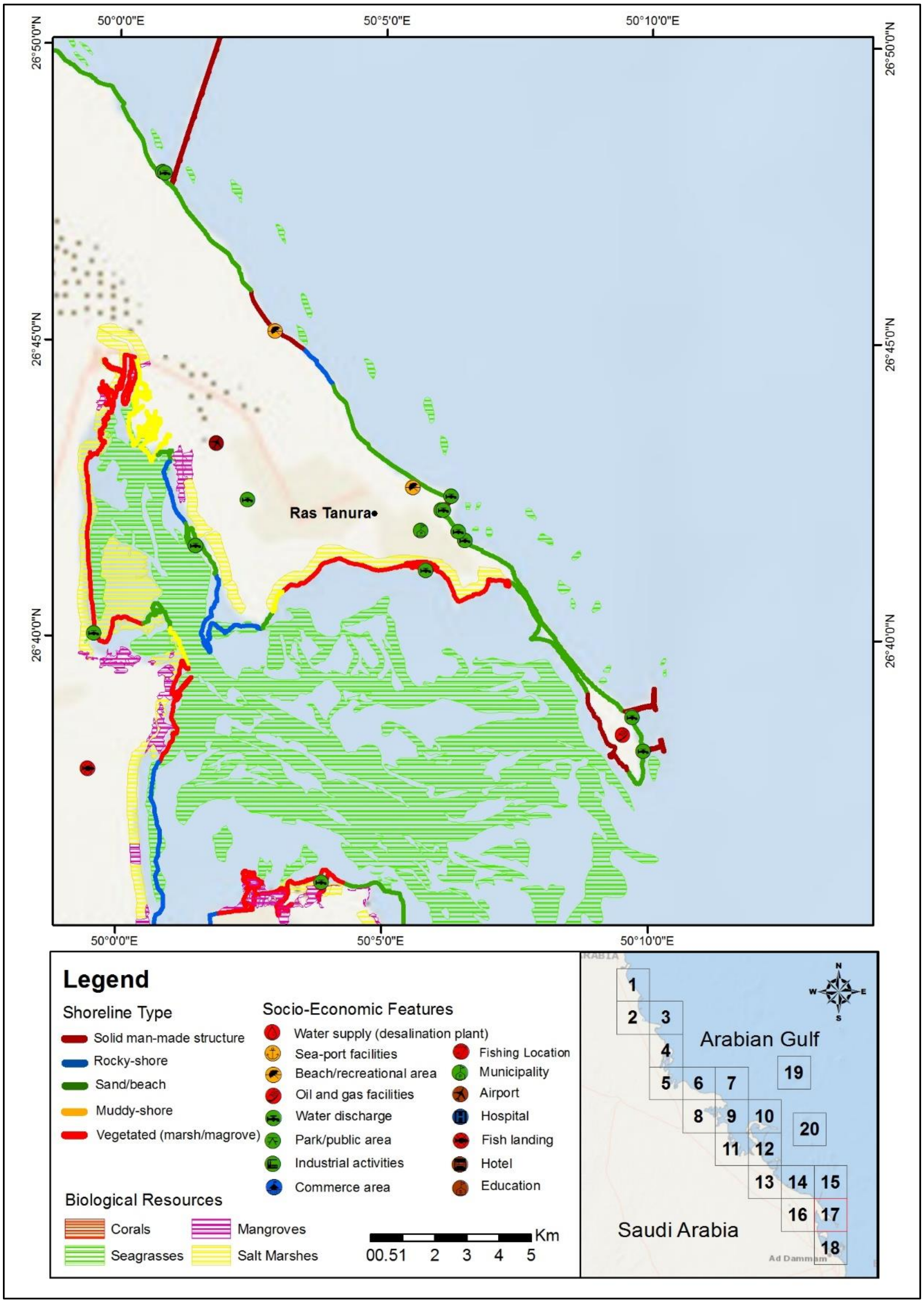


50°0'0"E
50°5'0"E
50°10'0"E
27°0'0"N
26°55'0"N
26°50'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
0 0.5 1 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 16


49°45'0"E
49°50'0"E
49°55'0"E
26°50'0"N
26°45'0"N
26°40'0"N
26°35'0"N
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
0 0.5 1 2 3 4 5 Km
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

- Grid 17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50°10'0"E
26°50'0"N
26°45'0"N
26°40'0"N
Ras Tanura
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
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2 3
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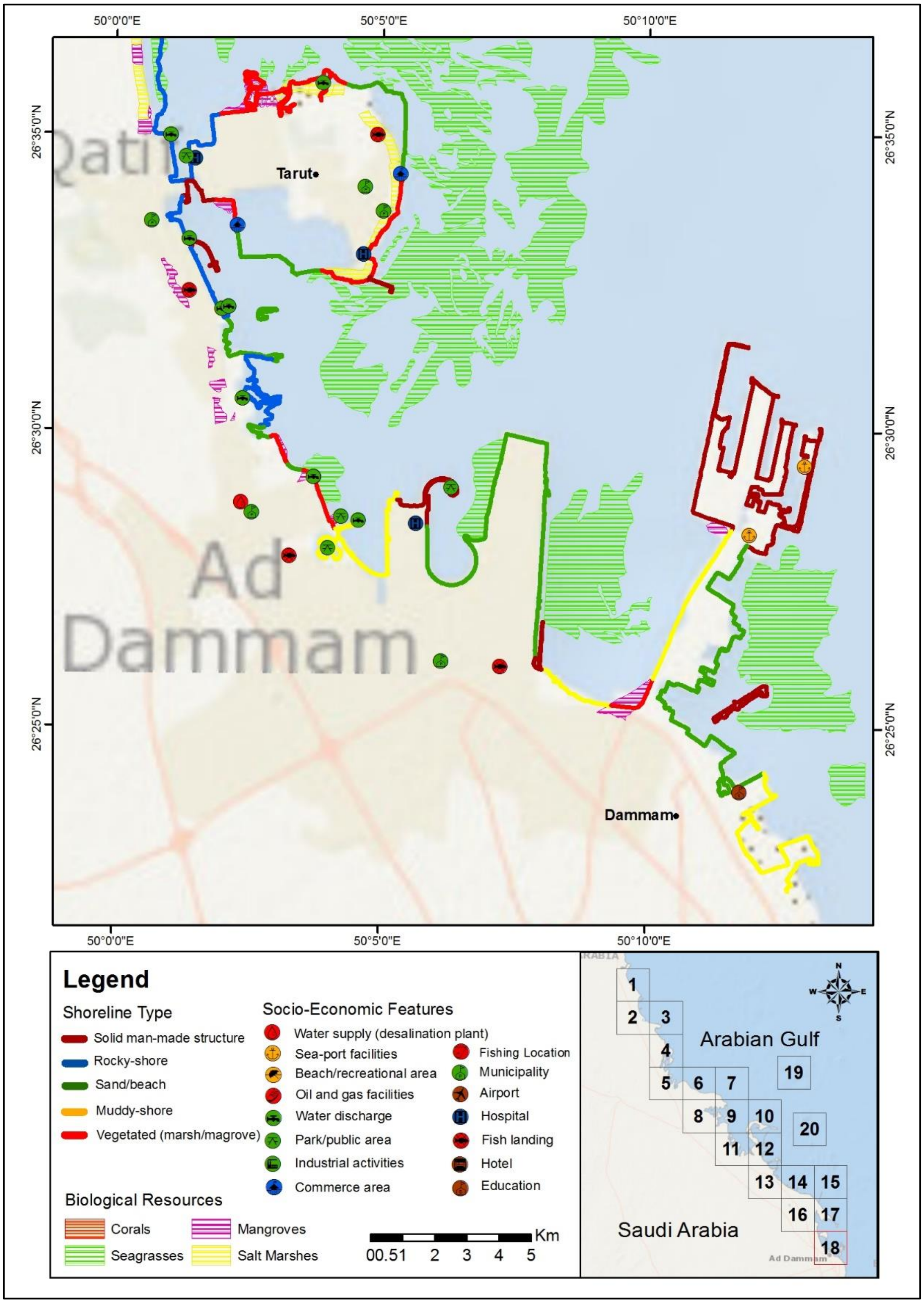
5 6 7
8 9 10
11 12
13 14 15
16 17
18
19
20

- Grid 18


50°0'0"E
50°5'0"E
50°10'0"E
26°35'0"N
26°30'0"N
26°25'0"N
Qatif
Tarut
Ad Dammam
Dammam
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
00.51 2 3 4 5
Km
Arabian Gulf
Saudi Arabia
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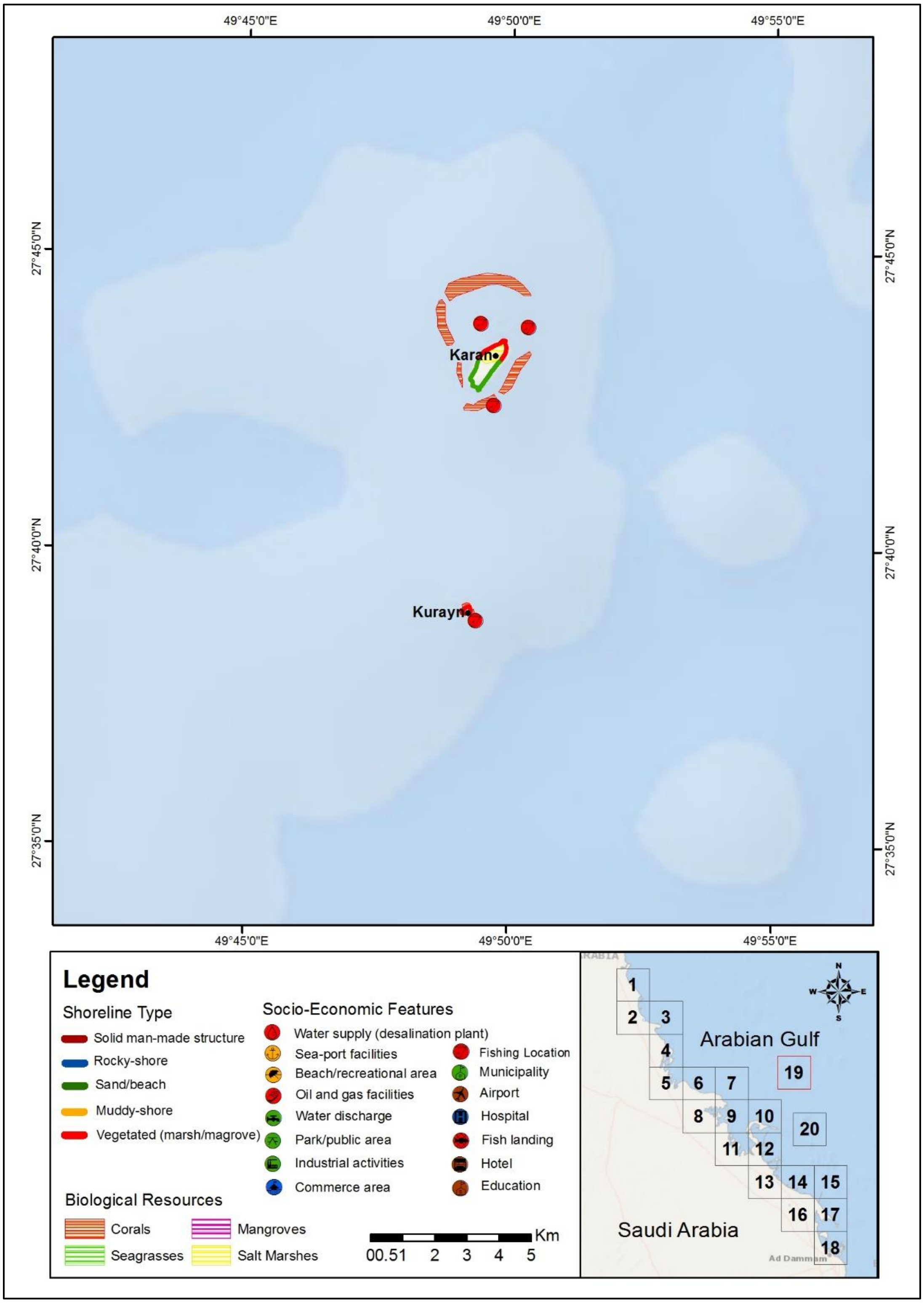
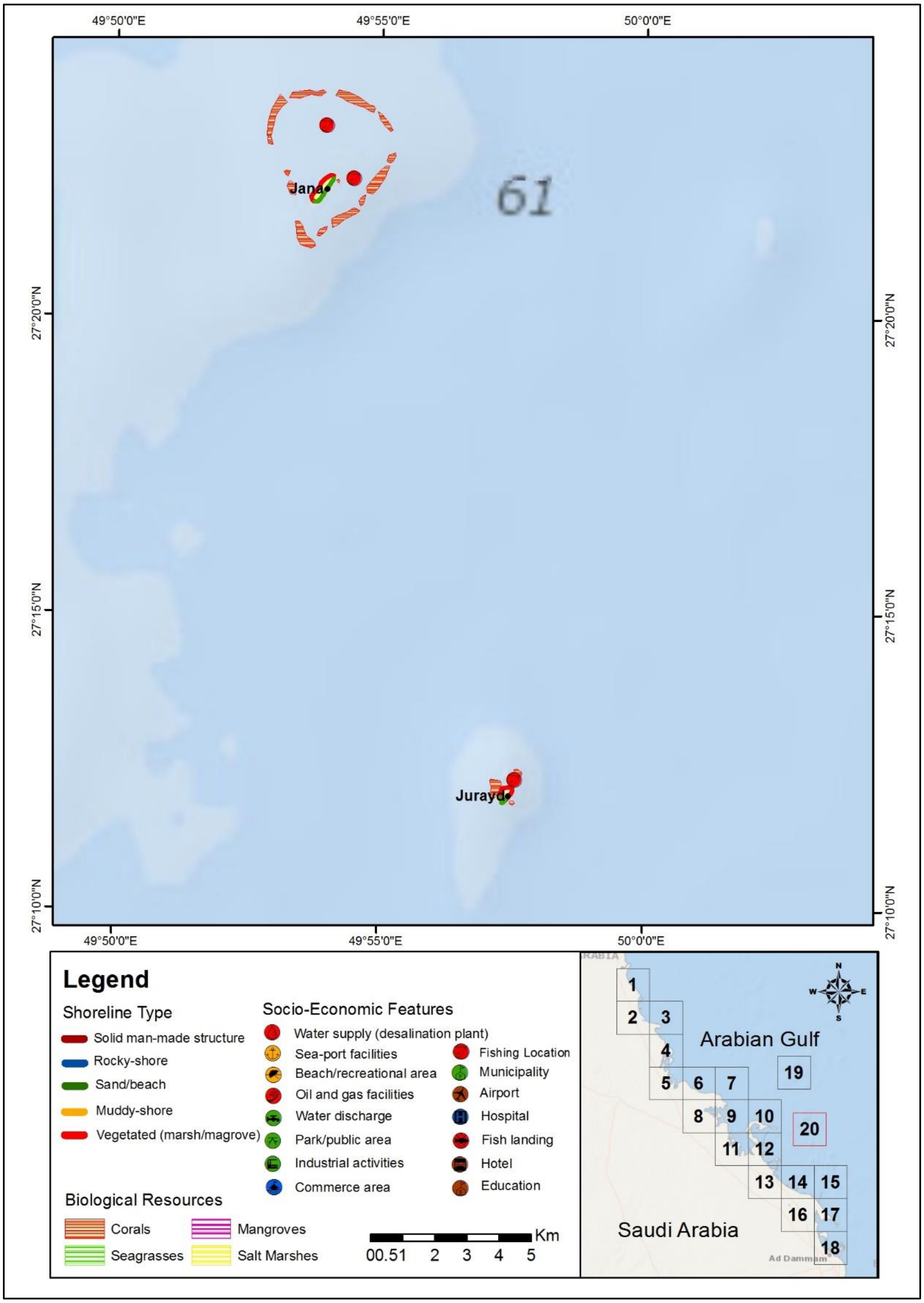
- Grid 19


49°45'0"E
49°50'0"E
49°55'0"E
27°45'0"N
27°40'0"N
27°35'0"N
Karan
Kurayn
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
Park/public area
Industrial activities
Commerce area
Fishing Location
Municipality
Airport
Hospital
Fish landing
Hotel
Education
Biological Resources
Corals
Mangroves
Seagrasses
Salt Marshes
Km
00.51 2 3 4 5
Arabian Gulf
Saudi Arabia
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
N S E W

- Grid 20


49°50'0"E
49°55'0"E
50°0'0"E
27°20'0"N
27°15'0"N
27°10'0"N
Jana
61
Jurayd
Legend
Shoreline Type
Solid man-made structure
Rocky-shore
Sand/beach
Muddy-shore
Vegetated (marsh/magrove)
Socio-Economic Features
Water supply (desalination plant)
Sea-port facilities
Beach/recreational area
Oil and gas facilities
Water discharge
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# Vitae

| | |
|---|---|
| Name | :Sudibyo Solikan Sardi |
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| Academic Background | :Bachelor Engineering (B.Eng) in Environmental Engineering from Sepuluh Nopember Institute of Technology (ITS), Surabaya |

Sudibyo joined KFUPM as a graduate student at Earth Sciences (Geosciences) Department in 2012. Prior to join KFUPM he worked as junior lecturer in Environmental Engineering Department-ITS, Surabaya where he was involved in different environmental studies in Surabaya, under Air Pollution Control and Climate Change Laboratory.

He has background in environmental engineering that applicable with environmental science. His thesis is about environmental management in coastal area entitled with "Mapping of Environmental Sensitivity in the Western Arabian Gulf using Geographic Information System (GIS) for Oil Spill Response" under supervised Dr. M. A. Qurban. Last year, He has got as 3rd winner (Best poster in Basic Science and Engineering) in Student Scientific Conference that held by Ministry of Higher Education, Kingdom Saudi Arabia, in Riyadh. His scientific poster that time entitled with "Satellite Observations of Phytoplankton Distribution as Chlorophyll a in relation to Physico-chemical Parameters in Arabian Gulf". He also worked part-time as Research Scientist (GIS Analyst) in Center of Environment and Water (CEW), Research Institute-KFUPM, as GIS Analyst from September 2013 – December 2015.

He was involved in several professional associations i.e. member of Environmental Technology Management Association (ETMA) - Saudi Arabia, member of Association for the Sciences of Limnology and Oceanography (ASLO), and Member of Dhahran Geosciences Society, Saudi Arabia. Besides that, he (with the team) won in 2$^{nd}$ Venture Concept Competition, Entrepreneur Institute – KFUPM, Saudi Arabia, with project name "AIN-View, explore the experience to discover".